Restoration of the San Francisco Bay-Delta-River System: Choosing Indicators of Ecological Integrity

Prepared for the
CalFed Bay-Delta Program &
U.S. Environmental Protection Agency

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ENVIRONMENTAL DEFENSE FUND

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EXECUTIVE SUMMARY

Current state and federal policy initiatives provide an unprecedented opportunity to design a restoration program and implement "whole-ecosystem" management for the San Francisco Bay/Delta/River system, defined here as the watersheds of the Sacramento and San Joaquin Rivers, their delta, and the San Francisco Bay. A fundamental prerequisite for the success of this effort is to develop a solid scientific foundation for defining and monitoring the current health of the system, determining initial restoration and management needs, and evaluating the success of the program once it is underway.

Providing this scientific foundation for restoration can be accomplished by developing a suite of ecological indicators within a sound conceptual framework. An ecological indicator is an attribute of the system that can be measured to provide information about the health or integrity of that system -- in much the same way that the temperature of a patient provides a doctor with diagnostic information about the patient's overall health. Using a logical conceptual framework to develop the indicators is useful to assure that both the suite of indicators and the restoration plan are comprehensive -- that they address the integrity of the system as an ecological whole, as well as each of the component parts.

This report describes the development of such a framework, as well as the development of a provisional list of ecological indicators, for the San Francisco Bay-Delta-River system. The framework and indicators were developed by regional and international experts at two workshops sponsored by the Center for Sustainable Resource Development at the University of California at Berkeley, the Environmental Defense Fund (EDF) and The Bay Institute of San Francisco (TBI).

The workshop participants proceeded according to Keddy et al.'s (1993) four step process for developing ecological indicators: (1) define ecological integrity or health in an operational way by defining the goals and objectives of the program; (2) select appropriate indicators that relate to these objectives; (3) identify target levels of selected indicators; and (4) develop a monitoring system to provide feedback. In general, the first workshop focused on step 1, while the second workshop focused on step 2. Steps 3 and 4 are subjects for future work.

During the first workshop, participants generally supported the ecosystem quality goal already defined by the "CalFed" program, an interagency group charged with designing and implementing ecosystem restoration for the Bay-Delta system. Their adopted goal is to: "improve and increase aquatic and terrestrial habitats and improve ecological functions in the Bay-Delta to support sustainable populations of diverse and valuable plant and animal species." In addition, participants of both workshops seemed to share a common goal of enhancing the self-sustaining qualities of the system, as opposed to moving in the direction of an increasingly highly managed system. Combining these concepts, we refer here to the goal of Bay-Delta-River restoration and management as the **(re-)establishment of a healthy system that supports a diversity of habitat types along with their resident communities of plants and animals, supports essential ecological functions, and is self-sustaining (requiring minimal intervention) and resilient to stresses.** It is important to note that this definition asumes that the system will continue to accomodate human use of natural resources.

In order to proceed with on-the-ground restoration and management efforts, it is useful to expand this general goal into a series of more specific objectives. Building on previous efforts, participants in the second workshop developed lists of objectives that have been consolidated by the EDF/TBI staff into the following:

A. Ensure conditions necessary to support and protect native biodiversity;

B. Protect and/or restore conditions necessary to increase populations of valuable plant and animal species (in a manner consistent with protecting native biodiversity);

C. Ensure sufficient extent, diversity, quality, connectivity, and range of successional states of natural habitats;

D. Protect and/or restore the natural trophic structure of communities;

E. More closely approximate the natural patterns of transport of essential materials (water, sediments, nutrients);

F. More closely approximate the natural hydrological regime;

G. Protect and/or restore water quality;

H. Provide for societal uses (harvest, recreation, aesthetics).

These objectives reflect components and processes of the system that appear necessary to achieve the overall goal for the Bay-Delta-River system and to successfully implement the "whole-system" management envisioned by current law and policy.

In order to take the next step -- translating these objectives into a suite of indicators -- an ecologically sound conceptual framework is required to assure that the indicators include each of these key components and processes in a way that addresses the ecological integrity of the entire system (Bay-Delta-River) as well as the integrity of each of its smaller sub-units (such as Delta wetlands or particular anadromous fish species). An additional benefit of an explicit, scientifically defensible framework is to explain the importance and purpose of each indicator to policymakers and the public.

The premise of the framework used in the workshops to develop ecological indicators for the Bay-Delta-River system is as follows: **the suite of indicators is designed to provide measurable evaluations of key structural and functional attributes of the system at a range of hierarchical scales: the entire landscape, the ecological zones present within that landscape, and the major habitat types of each zone. Within each habitat type, indicators are classified as measures at the community/ecosystem or population/species levels of ecological organization.** This approach helps to ensure that all of the important attributes of the system are being addressed, and is consistent with current recommendations of the scientific literature.

Filling in the details of this framework requires several tasks: first, developing a zone and habitat classification scheme (a *typology*) to define the scales of interest; second, developing a set of indicators that, for each component of the typology (i.e., landscape, ecological zones, and habitat types) relate the restoration objectives to structural and functional properties; and last, screening the indicators with several criteria to select the most useful suite.

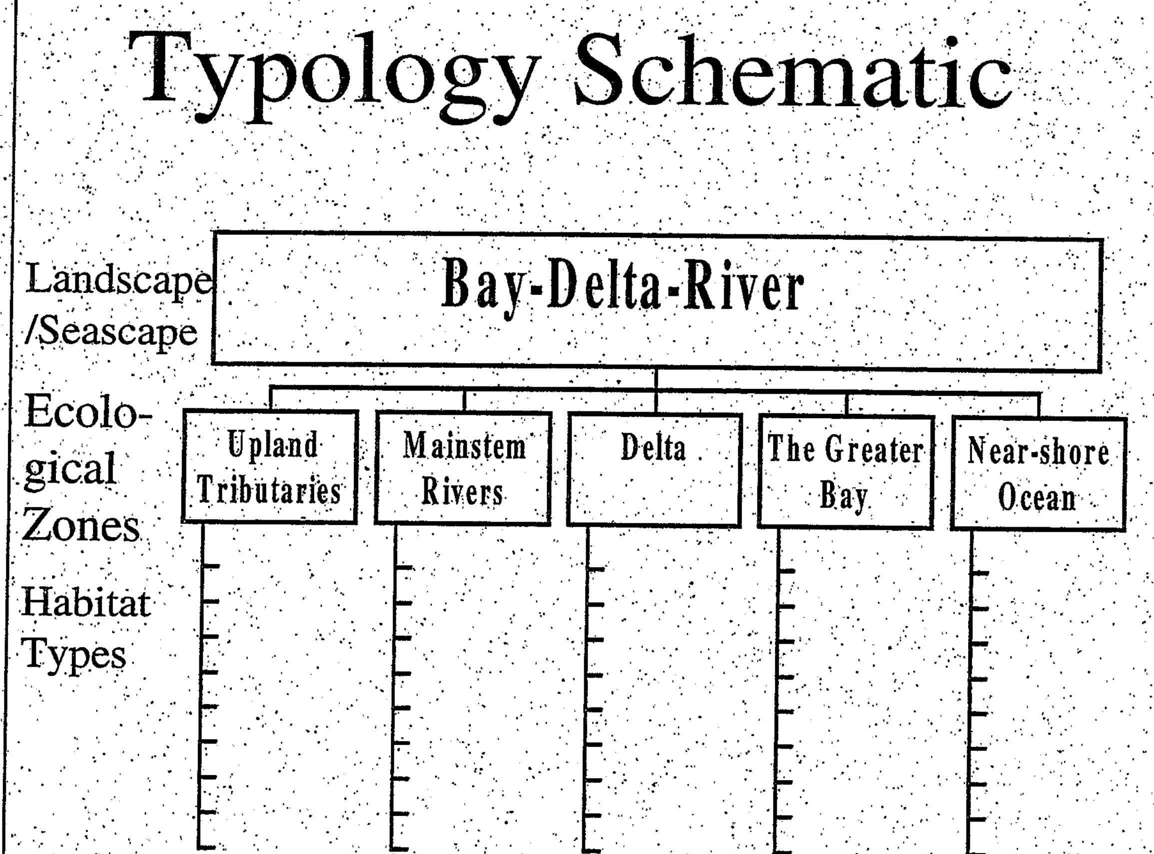


Figure ES-1: Schematic of the typology framework used for indicator development and organization, indicating the five ecological zones upon which workshop participants came to consensus.

The purpose of the typology, or classification scheme, is to consider the organization of the Bay-Delta-River system in a way that facilitates analysis and management, and also reflects the ecological organization of the system. Workshop participants developed the typology shown schematically in Figure ES-1. The landscape/seascape level is defined as the entire watersheds of the Sacramento and San Joaquin Rivers, their delta, San Francisco Bay, and the near shore ocean off the Golden Gate Bridge. The five major ecological zones are defined as:

--Upland Tributaries and Watersheds (from the headwaters to the juncture with mainstem rivers);

--Mainstem Rivers (the Sacramento and San Joaquin above tidal influence);

--The Delta (including the tidally influenced portion of the two mainstem rivers, and extending west to Chipps Island north to the confluence of the Sacramento and American Rivers, and south to Vernalis);

--Greater San Francisco Bay (from Chipps Island to the Golden Gate Bridge, and including Suisun Bay, San Pablo Bay, Central Bay, and South Bay);

--Near shore Ocean (a corridor extending 25 miles north and south of the Golden Gate Bridge and west to the continental shelf break).

The typology also includes a list of habitat types within each zone. Habitat-types defined at the workshop have been consolidated into a common format by the EDF/TBI staff (Table ES-1).

For each component of this typology, workshop participants developed a preliminary set of ecological indicators that represent both structural and functional attributes of the system. An ecological indicator is a measurable quantity that provides information about a property of the system that relates directly to overall health (and therefore to the objectives). The workshop's ground rules specified that the indicators should be ecologically relevant and scientifically defensible, and preferably fit an additional list of criteria that includes ease of measurement, sensitivity, and other similar characteristics.

Table ES-1: Expanded Habitat Typology for the Bay-Delta-River system. Water column, benthic, edge, and other habitats are given for each ecological zone.

	UPLAND TRIBUTARIES	MAINSTEM RIVERS[1]	DELTA	GREATER BAY	NEARSHORE OCEAN
Water Column Habitats	• Pools/riffles • Runs/glides	• Pools/riffles • Runs/glides	• Riverine • Flooded islands • Mixing zone • Sloughs	• Shallow (<? m) • Deep (>? m) • Mixing zone	• Marine • Freshwater plume
Benthic Habitats	• Unconsolidated -Gravel -Sand -Boulders	• Unconsolidated -Gravel -Sand -Mud	• Unconsolidated -Mud -Sand	• Unconsolidated -"unvegetated" -vegetated • Consolidated	• Unconsolidated • Rocky reef • Kelp beds
Edge Habitats	• Riparian • Floodplain	• Riparian • Floodplain	• Tidal marsh • Non-tidal marsh • Riparian • Floodplain	• Marine marsh • Brackish marsh • Freshwater marsh • Other vegetated • "Unvegetated" intertidal	• Rocky intertidal • Beach • Wetlands
Related Habitats				• Small streams • Managed marshes	• Offshore islands • Dunes

A sample list of indicators, for the landscape level, is shown in Table ES-2; the complete list of indicators is presented in the full report. Some of the indicators that were suggested at the workshop are readily measurable, while others are properties that cannot be measured directly, but are valuable for assessing the health of the system. In order to distinguish the two, and to integrate all of the results into a common format, the table presents "property assessed" and "indicator" explicitly. Italicized entries were added after the workshops by the EDF/TBI staff for clarity, based on notes from the workshop. Relevant objectives (by letter designation) are also noted.

The indicators derived at the January workshop provide a solid starting point for full development of a suite of indicators for the Bay-Delta-River system. The next stage of the process will involve refining this suite of indicators, and establishing target values for each. Using the framework, typology, and preliminary suite of indicators developed

[1] Mainstem rivers can be further separated into three geomorphic divisions: an upstream reach, dominated by pools and riffles, a middle reach consisting of an active meander zone, and a lower reach being a low-gradient floodplain. For consistency among the ecological zones, these three reaches are combined here.

Table ES-2: Indicators at the landscape level developed at the workshop

LANDSCAPE		
OBJ.	PROPERTY ASSESSED	INDICATOR
ALL	*S1. Landscape integrity*	• Sum ecological zone indicators across the landscape (% of elements)
A, B, C	*S2. Habitat quality*	• Natural channel density and complexity
A, B, C, D	*S3. Habitat diversity*	• Proportional representation and area of all habitats
A, B, C, E, H	**S4**. Connectivity of habitats (corridors)	• Distance between interacting habitat types ("feeding stations") • Average distance between nesting and foraging habitats for (resident) birds • Total number of temperature/physiochemical barriers to salmon migration • Number of barriers/bottlenecks to movement of motile/migratory organisms
C, E, F, G	**F1**. Natural water flow regime	• Variability in flooding duration and frequency
C, D, E, G	*F2. Natural sedimentation regime*	• Sediment flux and distribution • Sediment delivery to the estuary
A, B, D, E	**F3**. Total landscape productivity	
		• Morphometry of the estuary (related to tidal prism)

through this project, each component of the typology can be addressed and refined in turn. A separate group of experts for each of the different components of the typology, capitalizing on the expertise in existing programs, may be the most appropriate forum for indicator refinement. Indicators that are part of existing monitoring programs should be retained if they meet the criteria for selecting indicators described in Chapter III.

The refined suite of indicators will provide a valuable tool for screening restoration projects, evaluating restoration measures, and for implementing adaptive management.

I. INTRODUCTION AND BACKGROUND

A. Policy Context

Provisions of the Bay-Delta "Accord"[1] and Central Valley Project Improvement Act (CVPIA), combined with requirements of the Endangered Species Act and the Clean Water Act, provide an unprecedented opportunity to design and carry out protection and restoration measures for the San Francisco Bay-Delta-River ecosystem. This complex ecosystem is defined here as the watersheds of the Sacramento and San Joaquin Rivers, their delta, and the San Francisco Bay (see Figure 1). Within the context of each of these separate initiatives, new emphasis has been placed on the development of a comprehensive, whole-ecosystem plan for Bay-Delta-River restoration and management. This ecosystem-based approach is supported by a broad range of constituencies as the best means of not only protecting the environment, but also providing some predictability regarding future environmental responsibilities for water users.

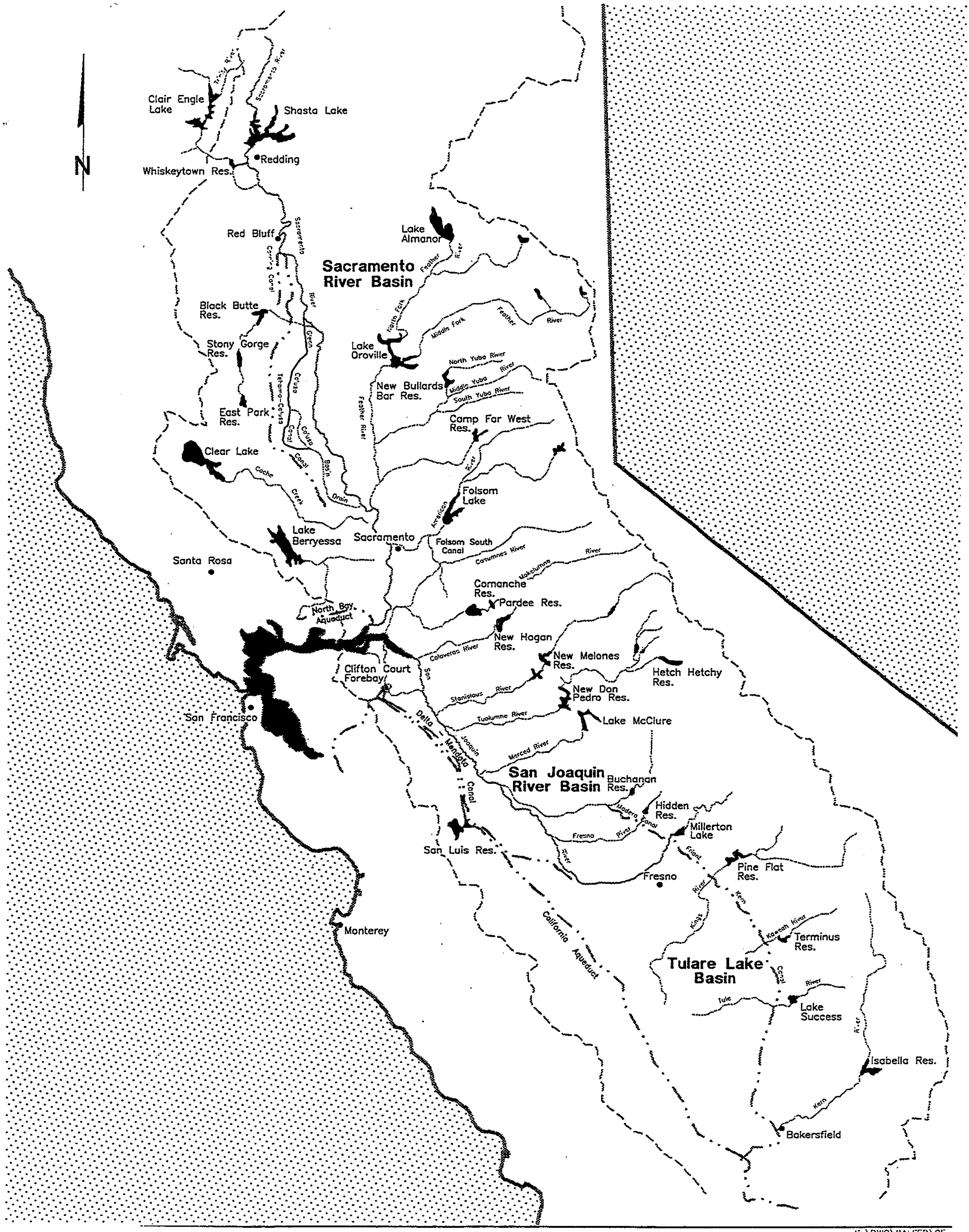
In addition to the goal of effective whole-ecosystem management, each of these state and federal initiatives contains specific requirements for protecting or enhancing populations of particular species and the habitats and processes-- such as water flow regimes-- that support them. Significantly, both the Accord and the CVPIA provide new tools for implementing these restoration measures, in the form of both river flow requirements and mechanisms to fund additional flows and habitat improvements.

A fundamental prerequisite for the success of these efforts is to develop the scientific foundation needed to define and assess the "health" of the ecosystem, determine which types of restoration or management projects are most likely to produce the desired results, and provide the tools for evaluating the success of these projects.

[1] "Principles for Agreement on Bay-Delta Standards Between the State of California and the Federal Government," signed on December 15, 1994 by representatives of various stakeholder interest groups as well as California and federal government officials.

Figure 1

The Bay-Delta-River System



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In addition, as part of this foundation, *an ecologically sound conceptual framework would be useful for translating the "whole-system" approach into practice.* The purpose of an explicit, scientifically defensible framework is to assure that the ecological integrity of the entire system (Bay-Delta-River)-- as well as the integrity of each of the component parts (such as Delta wetlands or particular anadromous fish species)-- is considered. The National Research Council (1992) has recommended this approach, stressing comprehensive ecosystem management.

The development of a logical and easily understandable conceptual framework has several additional benefits: it helps ensure that the restoration plan is comprehensive, reducing the likelihood of failing to consider significant system attributes, functions, or services; it helps to efficiently integrate all of the components of the restoration plan into a coherent whole; it facilitates the determination of priorities among restoration actions; and it helps to explain the importance and purpose of each action to policymakers and the public.

B. The Role of Ecological Indicators

Although whole-system planning and ecological health are intuitively understandable concepts (see Box 1), capturing them with an *operational* definition is challenging, particularly in large, diverse, and highly modified ecosystems such as the San Francisco Bay-Delta-River. One approach is to use *ecological indicators* to measure ecosystem health, in the same way that a doctor takes the temperature of a patient to provide diagnostic information about his/her overall health. An ecological indicator is a measurable quantity that provides information about a property of the system that relates directly to overall health. For example, the areal extent of various classes of riparian vegetation (indicator) assesses habitat heterogeneity (property) along river banks, which is directly related to maintaining biodiversity. Thus indicators bridge the gap between "real world" science and intuitively desirable but less easily defined ecosystem properties such as "health", "integrity", "resilience", and "self-sustainability".

How does one go about choosing the most useful indicators? Although many factors (scientific, economic, and sociopolitical) enter into play, the fundamental requirement is that the most important attributes of the ecosystem be represented. This is the role of the conceptual framework alluded to above. Two essential characteristics of this framework are that *both structural and functional attributes* of ecosystems need to be assessed and that this should be done *at a variety of scales* (see, e.g., National Research Council 1992; Noss 1990).

Structural attributes refer to the physical components of the system and their spatial relationships to one another. For example, spawning areas containing suitable gravels must be available for anadromous fish, and these areas must be connected to migration corridors. *Functional* attributes are the processes at work in the system. To continue our example, hydrological processes must keep the spawning gravels from becoming silt-laden.

Determining ecological indicators at many *scales* helps to ensure consideration of the whole as well as the parts and ensures that large scale processes work in harmony with processes and structures at smaller scales. Relevant scales may include the entire landscape, well-defined regions or ecological zones, habitats and communities, or populations. Formulated in this way, a comprehensive suite of ecological indicators for the Bay-Delta-River system will provide managers with a useful tool to define, assess, and monitor the health of the system. The evaluation of success or failure of management actions is essential for adaptive management (defined as the timely modification of management measures in response to results of actions taken and consciously designed management experiments; Lee 1993).

C. A Process for Developing Ecological Indicators

The Center for Sustainable Resource Development at the University of California, Berkeley (CSRD), the Environmental Defense Fund (EDF), and The Bay Institute of San Francisco (TBI) convened two workshops of local, national, and international experts in October, 1995 and January, 1996 to initiate the process of developing ecological indicators for the Bay-Delta-River system. Funding for the workshops was provided by the U.S. Environmental Protection Agency and by CalFed, the federal-state interagency group responsible for developing a long-term plan for managing the Bay-Delta estuary pursuant to the Bay-Delta Accord. The workshop agendas, minutes, background materials and lists of participants are attached as Appendices A and B.

The purpose of these workshops was twofold: **to agree on a conceptual framework for indicator development,** and **to develop a provisional list of indicators.** The results of these efforts are presented in the body of the report.

The authors anticipate that the next step in this process will be to use both the framework and the provisional indicator list as a foundation for a more rigorous and detailed evaluation of ecological indicators. The framework provides a logical method for breaking down the process of developing indicators into smaller, more manageable units, so that this next step can be accomplished by focused groups of experts. The refinement of the indicator list will provide an opportunity to, whenever appropriate, incorporate indicators that are already being monitored or assessed in ongoing programs.

BOX 1: WHAT IS ECOSYSTEM HEALTH?

One challenge in protecting the integrity of the entire Bay-Delta-River system (and the species that depend on it) is simply determining what a healthy ecosystem is. *Ecosystem health* has been described in a variety of ways. Karr (1993) defines ecosystem health as the condition in which a system realizes its inherent potential, maintains a stable condition, preserves its capacity for self-repair when perturbed, and needs minimal external support for management. *Biological integrity* refers to the "ability of an ecosystem to support and maintain a balanced, integrated, adaptive biological community having a species composition, diversity, and functional organization comparable to that of natural habitat in the region" (Karr and Dudley 1981).

The following components of ecosystem health have been defined and used in the scientific literature:

Ecosystem health descriptor	Definition
Costanza (1992):	
Homeostasis	Maintenance of a steady state in living organisms by the use of feedback control processes
Absence of disease	Lack of stress, or perturbation with particular negative effects on the system
Diversity/Complexity	Evenness and richness of species.
Stability/resilience	How fast the variables return towards their equilibrium following a perturbation.
Vigor/scope for growth	Overall metabolism or energy flow
Balance	Existence of proper balance between system components
Westman (1978):	
Resilience	Degree, manner, and pace of restoration of initial structure and function in an ecosystem after disturbance
Inertia	Ability of a system to resist displacement in structure or function when subjected to a disturbing force
Elasticity	Time involved in restoration
Amplitude	Degree of brittleness of the system; threshold beyond which ecosystem repair to the initial state no longer occurs
Hysteresis	Degree to which the pattern of recovery is not simply a reversal of the pattern of initial alteration
Malleability	The ease with which the system can become permanently altered; compare the new stable state to the former one
NRC (1992):	
Persistence	The ability of the ecosystem to undergo natural successional processes or persist in a climax sere, all without active human management
Verisimilitude	A broad, summative, characteristic of the restored ecosystem reflecting the overall similarity of the restored ecosystem to the standard of comparison, be it prior conditions of the ecosystem or of a reference system

Developing a more explicit definition of ecosystem health is part of the task of practitioners in the emerging fields of *ecosystem medicine*, *stress ecology*, and *clinical ecology*. These researchers have most often defined the concept of ecosystem health by what it is *not*. David Rapport and colleagues (e.g., 1984; 1989; Rapport, Regier and Hutchinson 1985; Rapport, Regier and Thorpe 1981; Rapport, Thorpe and Regier 1979) developed the concept of an *ecosystem distress syndrome*, marked by reductions in the stability and diversity of aquatic ecosystems, elimination of the longer-lived, larger species, and a tendency to favor short-lived opportunistic species (Rapport, Regier &

Hutchinson 1985). Rapport et al. (1981) compare the stress response of an ecosystem (considered as an organism) to that of a mammalian system. The first response to stress is generally an alarm reaction (a characteristic change at the first exposure to stress), followed by resistance (when continued exposure leads to an adaptation); and, finally, exhaustion (irreversible damage following prolonged exposure).

This field of study is not limited to pure theory. In the Great Lakes, some of the more heavily used, degraded subsystems exhibit the general distress syndrome. In case studies of the subsystems, likely ecological responses from each type of stress can be inferred from impact assessments, thus guiding rehabilitation efforts (Rapport, Regier, and Hutchinson 1985). The five main groups of ecosystem stresses identified include: (1) harvesting of renewable resources; (2) pollutant discharges; (3) physical restructuring (including hydrologic modifications); (4) introduction of exotics; and (5) extreme natural events (Rapport, Regier & Hutchinson 1985).

II. DEFINING ECOSYSTEM HEALTH USING A SUITE OF ECOLOGICAL INDICATORS

Several methods of generating a suite of indicators have been developed in various kinds of ecosystems. For the purposes of our workshops, we followed the logical process suggested by Keddy et al. (1993) for translating the ideas of ecosystem health into practice and establishing ecological indicators:

(1) define ecological integrity or health in an operational way;
(2) select appropriate indicators of health or integrity;
(3) identify target levels of selected indicators; and
(4) develop a monitoring system to provide feedback.

Because our efforts were directed at developing indicators, we attempted to take the process through Step 2, and to do this in such a way as to lay the groundwork for Steps 3 and 4.

A. Step 1: Define Ecosystem Integrity/Health in an Operational Way

Step one constitutes the development of general goals of ecosystem management or restoration program. During the two workshops, some confusion-- in part semantic and in part substantive-- was expressed over the terms *goal*, *objective*, *ecosystem service*, and *indicator*. We define these terms as follows: (1) *goals* describe the 'big picture' overview of what the restoration program is trying to achieve; (2) *objectives* are more precise descriptions of the particular steps necessary to achieving the program goal; (3) *ecosystem services* are benefits that a healthy ecosystem provides to its residents, including humans, and are a subset of the objectives; and (4) *indicators* are measurable quantities that allow us to assess or evaluate the state of the system.

In Keddy et al's (1993) formulation, the *goal* should be established first. The more specific *objectives* and *services* should also be defined as part of Step 1, but can be refined as necessary during the development of the indicator framework (Step 2). Ranges for *indicators* are developed during Step 3, and provide specific quantitative targets for restoration and management programs. The order of the steps is somewhat iterative; indicators can be developed for each particular *objective* or *service*, but *objectives* and *services* may also arise from considerations of ecological structure, function and services taken into account while developing indicators. For a further discussion of this issue, see Keddy's paper (p.59).

Goals

During the October workshop, a substantial proportion of the presentations and discussion focused on the definition of the *goal* that should guide the future management of the Bay-Delta-River system. Participants generally supported the goal statement offered by CalFed for ecosystem quality: "Improve and increase aquatic and terrestrial habitats and improve ecological functions in the Bay-Delta to support sustainable populations of diverse and valuable plant and animal species." In addition, participants of both workshops also seemed to share a common goal of enhancing the self-sustaining qualities of the system, as opposed to moving in the direction of an increasingly highly managed one. This was referred to as the *physis* approach (restoring physical processes that promote self-healing and maintenance), as opposed to reliance on continual intervention. This approach has proved successful in other large river ecosystems, such as the Rhine and Kissimmee (see p. 61 and Box 2).

We combined these concepts to synthesize the goal of Bay-Delta-River restoration and management as the **(re-)establishment of a healthy system that supports a diversity of habitat types along with their resident communities of plants and animals, supports essential ecological functions, and is self-sustaining (requiring minimal intervention) and resilient to stresses.** It is important to note that this definition assumes that the system will continue to accommodate human use of natural resources. Restoration as used here does not mean attempting to regenerate the pre-disturbance system per se, but rather to restore essential characteristics that allow the system to function in the manner desired.

Objectives / Services

The overall *goal* provides a paradigm for restoration of the Bay-Delta-River system. On-the-ground restoration efforts, however, require more specific program *objectives.* Both CalFed and the San Francisco Estuary Project's *Comprehensive Conservation and Management Plan* (CCMP) produced lists of ecosystem quality objectives to this end. Participants in an earlier workshop, "Goals for Restoring a Healthy Estuary", sponsored by the Natural Heritage Institute (NHI) and others, concluded that "concepts such as 'ecosystem health' and 'ecosystem integrity' are of limited use in setting ecosystem restoration goals because they cannot be precisely defined in terms of measurable ecosystem functions, processes, or properties" (NHI 1995). The participants favored defining ecosystem restoration goals in terms of a system's capacity to provide the full range of ecosystem "services" necessary to support both native biological communities as well as human uses of the system resources (see Table 2 of Appendix A-1 for a consolidated list of the objectives and services suggested by these groups).

At the January workshop, most of the breakout groups generated lists of objectives during the process of developing indicators. These objectives were generally consistent among groups, although worded in different ways. In Chapter V (Table 2), we present a list of restoration objectives, synthesized from those proposed in the breakout groups and the ecosystem services identified at the NHI workshop.

B. Step 2: Select Appropriate Indicators of Health or Integrity

Ecological indicators provide measurements of the properties or attributes of the system that are most relevant to achieving the overall goal and objectives. In choosing ecological indicators, an explicit framework is useful to ensure that the suite of indicators reflects all of the important properties of the system. Indicators should be developed at multiple scales of ecological organization. In other words, indicators that reflect properties relating to the entire system should be developed, as well as indicators that relate to particular subelements, like specific habitats within the system. In addition, at each level of organization, both structural and functional attributes should be included. By structural attributes, we refer to the system's *physical characteristics* (including the makeup of its biological communities) and their spatial relationships.[2] Functional attributes include the ecological and evolutionary *processes* at work in the system. Of course, structural and functional attributes are often related; for example, bathymetry (structural) is a result of geography and hydrology (functional). Therefore, the distinction between a structural attribute and a functional one is not always clear. However, the distinction is useful to help ensure that all important attributes are assessed, and is common in the scientific literature (see e.g., NRC 1992).

Ecological indicators allow us to objectively evaluate these properties or attributes. Some key properties are directly measurable. For those that are not, surrogate measurements are used. In all cases, the indicator is the *measurable quantity* used to assess the property or attribute.

C. Step 3: Identify Thresholds and Target Levels of Selected Indicators

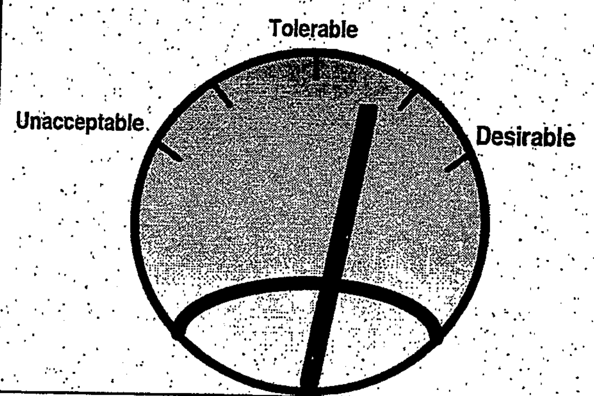
Once indicators are selected, a range of target values, from tolerable to desirable levels, should be developed for each (See Figure 2).

Because determining the target range of indicator values from first principles is difficult, comparisons with reference systems or historic states are sometimes used. Reference systems can be used to infer how a system with ecological integrity might look and/or function. Another technique is to reconstruct how the system looked and functioned in the past, and compare it with how it functions now. This the approach used in the Florida Everglades, where a natural system model is being designed to serve as the template for restoration (see Box 2). In disturbed ecosystems such as the Bay-Delta-River system, it is clearly unreasonable to strive for the restoration of pristine conditions,

[2] This definition combines the concepts of structure and composition that are often treated as distinct in the ecological literature.

because certain changes in the system (e.g., water diversions and urban development) are irreversible. However, an analysis of historical conditions and processes can provide insights into realistic target levels. Limitations of this approach include limited or poor quality data for past time periods and difficulties in determining causality. Another useful tool is the analysis of comparable reference ecosystems in more pristine conditions, if they exist. This method can be difficult to apply to large, complex ecosystems which tend to be unique.

Figure 2: A numerical range should be set for each indicator selected, from unacceptable to desirable levels.



D. Step 4: Develop a Monitoring System to Provide Feedback

By monitoring changes in the ecological indicators, scientists and decision makers can determine whether the management and/or restoration program is having its intended effect. Monitoring also provides the foundation for *adaptive management*. Because the behavior of biological systems is often difficult to predict, flexibility is key in restoration projects. In general, pilot studies are also recommended, in order to define, evaluate, and calibrate the indicators prior to full-scale implementation of the program (Kremen 1992). The demonstration project carried out on the Kissimmee River in Florida provides an excellent model (see Box 2).

Ongoing uses of ecological indicators include short-term evaluation of success of a project and long-term monitoring. The Bay-Delta-River system is already monitored by a variety of programs that can serve these functions. We anticipate that step 4 of the process will be taken up by others, including the Interagency Ecological Program as part of their redesigned long-term monitoring efforts.

Monitoring can be designed in part to be used for public outreach. For example, simplistic indicators of ecosystem health, such as the Chesapeake Bay white sneaker visibility test (a proxy for water clarity), may not be scientifically defensible, but can help inform the public about restoration efforts in their region.

BOX 2: RESTORATION OF THE KISSIMMEE RIVER

The Kissimmee River basin is located in central Florida between the city of Orlando and Lake Okeechobee within the Coastal Lowlands physiographic province (Koebel 1995). The historic Kissimmee River meandered for approximately 166 km within a floodplain that ranged from 1.5 to 3 km wide (Arrington 1995). Channelization of the river, started in 1962 and completed in 1971, resulted in the loss of approximately 14,000 ha of floodplain wetland habitats, as well as modification of the river into a series of impoundments which severely altered vegetation and animal communities by greatly simplifying what had been a complex, braided river-floodplain ecosystem. The 15-year restoration project planned for this system is expected to return approximately 70 km of contiguous river channel and 11,000 ha of wetland to a more natural condition (Cummins and Dahm 1995).

The Kissimmee River Restoration Project is a landmark case in restoration of large-scale systems. Recently, an entire issue of the journal *Restoration Ecology* was dedicated to the project. The steps taken by the researchers and policy-makers to develop a restoration evaluation program draw some parallels to the steps taken with regard to the Bay-Delta-River system. Here, we describe the process of developing the Kissimmee River Restoration Project in terms of Keddy et al.'s (1993) four-step process for developing a suite of ecological indicators.

Step One: Goals and Objectives

The goals for the Kissimmee River ecosystem have evolved over time, but the basic tenets, including a holistic, landscape-scale approach to restoration and a belief in the need to re-establish the natural hydrologic regime, have remained essentially the same.

The impetus for restoring the system came with the Kissimmee Restoration Act of 1976, which included three primary goals: 1) use natural and free energies of the river system, 2) restore natural seasonal water level fluctuations, and 3) restore conditions favorable to increases in abundances of the native biota (Karr 1994).

The most oft-cited forum for developing environmental restoration goals and objectives for this system is the Kissimmee River Restoration Symposium, conducted by the South Florida Water Management District (SFWMD) in 1988. The symposium emphasized an ecosystem approach to restoration with a single goal: **to restore the ecological integrity of the Kissimmee River** (Toth 1993). Ecological integrity was defined as the capability to support and maintain biological communities with a species composition, diversity, and functional organization comparable to that of the natural habitat of the region (Karr 1994).

Step Two: Indicators

First, a classification scheme (habitat typology) was developed for the Kissimmee River system, with five habitat types for the river channel, ten habitat types for the floodplain, and four habitat types for the channelized river. The organization of habitats into classes will form the basis for a sampling program that measures key abiotic and biotic indicators.

At the symposium, it was proposed that the ecological integrity of systems like the Kissimmee River is determined by five classes of variables, which serve as indicators of ecological integrity:

1) **source of energy**: type, amount and size of allochthonous inputs, primary production, and the seasonality of available energy;
2) **water quality parameters**: temperature, turbidity, dissolved oxygen, nutrient inputs, organic and inorganic chemicals, heavy metals, and pH;
3) **habitat quality**: substrate, water depth, current velocity, availability of habitat for all life-history needs, and habitat diversity;
4) **hydrologic conditions**: water volume and temporal variability of discharge; and
5) **biotic interactions**: competition, predation, disease, and parasitism (Koebel 1995).

As a follow-up to the symposium, the SFWMD, in July 1991, commissioned a scientific advisory panel to provide recommendations for development of a comprehensive ecological evaluation program. The advisory panel suggested that the restoration evaluation program should be conducted from an ecosystem perspective, which requires evaluation of *biotic* and *abiotic* conditions within the Kissimmee River Basin (Dahm et al. 1995). The panel also recommended that the restoration evaluation program have the following features:

1) provide a thorough understanding of ecosystem structure and function;
2) show direct cause-effect relationships between restoration measures and ecological responses;
3) include quantifiable biological responses and statistical comparisons; and
4) document ecological changes that are of both social and scientific importance (Toth 1993).

These features serve as criteria with which to choose the most appropriate indicators to monitor.

Step 3: Target Levels

The target values for indicators of the Kissimmee River Restoration Program are based on research and modeling of the historic structure and function of the system. Extensive research was carried out to establish how the system functioned in its pre-channelization state.

The various proposed restoration alternatives were evaluated according to five hydrological criteria, based on the prechannelization hydrograph (Karr 1994).

Step 4: Monitoring & Adaptive Management:

Implementation of the large-scale restoration measures has not yet begun, but the Kissimmee River Restoration Project has already taken steps to monitor the system. The advisory panel suggested, as part of a five-phase restoration evaluation program, that baseline conditions be established to define the current state of the Kissimmee River ecosystem, such that comparisons could later be made with conditions resulting from restoration (Koebel 1995).

Additionally, the SFMWD conducted a demonstration project, intended to resolve remaining technical issues regarding the various alternatives and to evaluate the feasibility of restoring the system's biological resources (Toth 1993). The goal of the demonstration project was to show that wetland vegetation and other wildlife would readily recolonize the reflooded areas, and riverine ecosystems would respond favorably to resumption of natural flow regimes. The SFWMD monitored the effect of hydrologic changes on floodplain vegetation, floodplain fish, secondary productivity, benthic invertebrates, and river channel habitat characteristics. Other agencies conducted alligator counts, bird surveys, fish population samples, water quality monitoring, and measurements of aquatic macroinvertebrate and periphyton responses (Berger 1992).

The demonstration project did not restore the Kissimmee River, but rather provided evidence indicating that restoration of ecological integrity of this river-floodplain ecosystem is possible (Toth 1993). This preliminary project provides an example of the utility of testing a restoration plan in a small area before applying it to the larger system. The demonstration project contributes to the aims of adaptive management; results and experiences of the demonstration project are already being used to guide planning, implementation, and monitoring efforts of the larger restoration project. Additionally, the validity of using historically based guidelines and criteria for developing a plan for restoring ecological integrity was verified by the demonstration project.

III. FRAMEWORK FOR DEVELOPING INDICATORS FOR THE BAY-DELTA-RIVER SYSTEM

A. Overview of the Conceptual Framework

According to the National Research Council (1992), restoration of an aquatic ecosystem requires coordinated, comprehensive management of all significant ecological elements, often on a watershed or other landscape scale. Similarly, the suite of ecological indicators that is developed for the Bay-Delta-River system should address each of the key ecological components and processes of the system. Successful implementation of this "whole-system" approach can best be assured by using a formal conceptual framework as an organizing tool to guide the development of the indicators. An additional benefit of using an explicit framework is to demonstrate the importance and utility of each of the indicators to policymakers and the public.

The premise of the framework for developing ecological indicators for the Bay-Delta-River system is as follows: **the suite of indicators is designed to provide measurable evaluations of key structural and functional attributes of the system at a range of hierarchical scales: the entire landscape, the ecological zones present within that landscape, and the major habitat types of each zone. Within each habitat type, indicators are classified as measures at the community/ecosystem or population/species levels of ecological organization.** By explicitly addressing several hierarchical levels of ecological organization, at multiple spatial scales, this framework attempts to assure that the integrity of the entire system, as well as each of its subunits, is addressed. This approach is consistent with current recommendations of the scientific literature (see Box 3).

Filling in the details of this framework requires several steps: developing a zone and habitat classification scheme or *typology* to define the scales of interest, and then developing a set of indicators that, for each component of the typology (i.e., landscape, ecological zones and habitat types), relate the restoration objectives to structural and functional properties. Lastly, this framework involves screening the suite of indicators with several criteria for ecological indicators to choose the best ones.

B. Development of a Habitat Typology

Comments by October workshop participants made it clear that a typology (zone and habitat classification system) should be developed in order to divide the Bay-Delta-River system into working units for analysis and management. A habitat typology is defined here to mean a hierarchical classification system depicting various major levels of ecological organization of the entire ecosystem. EDF and TBI proposed a strawman typology and solicited feedback on it from workshop participants, both through a questionnaire sent out in December and through a plenary session at the outset of the January workshop. This typology characterized the Bay-Delta-River system at three basic scales: 1) *the entire landscape* (in order to consider the interactions between each of the different components of the system); 2) *ecological zones* (corresponding to major biomes at the landscape scale); and 3) *habitat-types* (ecologically distinct areas within each ecological zone) (Figure 3). Indicators for each habitat type are further classified into two subunits of ecological organization: community/ecosystem or population/species. Under this schema, the *suite* of indicators for the Bay-Delta-River system as a whole therefore would incorporate a *set* of indicators for the entire landscape as well as *sets* for each component ecological zone and habitat type.

Once the basic ecological zone divisions were agreed upon by workshop participants, breakout sessions met (grouped by ecological zone) to develop a list of habitat types for each ecological zone. The results are presented in Chapter IV. The next step involved developing a set of indicators at the landscape scale, for each of the ecological zones, and for each habitat type within these ecological zones.

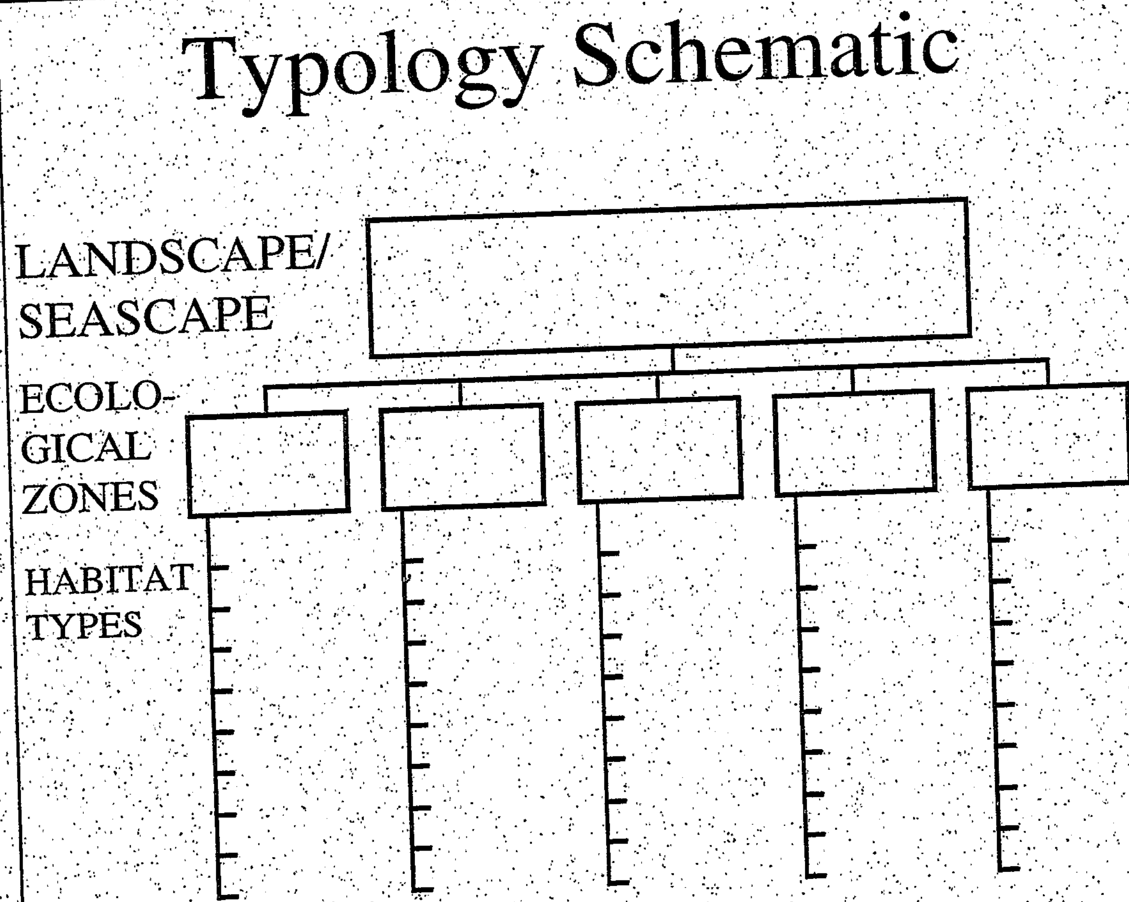


Figure 3: Schematic of the typology framework used for indicator development and organization. The first step is to establish a habitat typology by filling in the blanks, after which a set of indicators is developed for each box, addressing both structural and functional ecosystem attributes at several hierarchical scales of ecological organization. The *suite* of indicators incorporates a *set* of indicators for each component of this typology.

C. Development of a Suite of Ecological Indicators

The fundamental requirement of a suite of ecological indicators is that all of the important attributes of the system be represented. Accordingly, indicators should include both *structural* and *functional* attributes of an ecosystem. At the *landscape* level, connectivity of habitat types (measured as the geographic distribution of habitats) and hydrologic regime (measured as the variability in flooding duration and frequency) are examples of properties that relate to structural and functional indicators, respectively. A structural indicator for a given *habitat* might be age-structure of a population of interest, whereas primary productivity (measured by C-14 uptake rate) is an example of a functional indicator.

EDF and TBI offered a matrix for indicator development (Figure 4) which incorporates these levels of resolution, adapted from Noss' (1990) conceptual model of biodiversity at multiple levels of organization. In this model, compositional, structural, and functional biodiversity, shown as interconnected spheres, each encompass multiple levels of organization. Noss states that "this conceptual framework may facilitate selection of indicators that represent the many aspects of biodiversity that warrant attention in environmental monitoring and assessment programs." Our use of *structure* incorporates both the concepts of 'structure' and 'composition' as used by Noss. The matrix serves as a guiding principle and working tool for developing each set of indicators; it encourages development of a comprehensive, inclusive set of indicators for each ecological zone and habitat-type. Spaces are provided for both structural and functional indicators at the zone-level and, for each habitat type, structural and functional indicators at both the community and population levels. The matrix is useful not only in developing an initial set of indicators but also later, when refining this set, to identify gaps in knowledge of the health of the ecological zone or habitat type that the suite of indicators covers.

Figure 4: Matrix used by January workshop participants to guide indicator development

Indicator Development Matrix

For each Ecological Zone:

	STRUCTURE	FUNCTION
	A e.g. acreage of each habitat type (measured from aerial photos)	B e.g. rate of transport of material through the system (measured by flow)

For each Habitat Type:

	STRUCTURE	FUNCTION
Community/ Ecosystem	C e.g. fractal dimension of river banks OR species diversity/richness	D e.g. water temperature OR trophic relationships within the community
Population/ Species	E e.g. age structure OR population genetic parameters (e.g. polymorphisms)	F e.g. fecundity OR frequency of lesions, tumors, or disease in aquatic organisms

D. Criteria for Ecological Indicators

Ecological indicators have been defined in this paper as measurable attributes that allow us to assess the state of the ecosystem or its components. An inconsistency emerged from the workshops in that some groups confined their selection of indicators to such measurable attributes, while others listed certain key *properties* of the system that needed to be assessed, but were not in themselves directly measurable. For example, the "areal extent of wetlands" and "connectivity" of wetlands to some other habitat may both be considered key structural attributes of the system. However, while the former may be directly measured, the latter is not, but rather must be evaluated through a set of surrogate measures (e.g., amount of common boundary with another habitat; flow rates between other habitats and wetlands). We have therefore altered the format of Figure 4 to incorporate this discrepancy, distinguishing where necessary between *properties* of the system that workshop participants believed necessary to assess, and actual *indicators*. This distinction is useful here to faithfully report the outcome of each group's deliberations, but at the same time clearly point out where further work is needed to refine the actual set of indicators that might be most useful to managers.

In developing and refining the suite of ecological indicators, criteria for what makes a valuable indicator should be kept in mind. Some criteria we classify as *essential*: indicators <u>must</u> be (1) ecologically relevant and (2) scientifically defensible. An ecologically relevant indicator is closely related to or reflective of key ecological characteristics of a system or habitat. Scientifically defensible indicators are quantitative, with sufficient accuracy and precision to allow for ready interpretation. The relationship of an indicator to the property it reflects should be unambiguous and demonstrable. These criteria for scientific defensibility were based on criteria developed in the NHI workshop. Exceptions to the *essential* criteria may be made if a certain indicator has significant public appeal, high economic significance, or is especially relevant to policy-makers for some other reason.

Other criteria define beneficial, but not crucial, qualities of indicators. These *desirable* qualities include: (1) ease of measurement, (2) sensitivity (quick response to stress/perturbation; ability to provide early warning of disturbance), (3) existence of a historical database, (4) benign to measure (monitoring of the indicator is not damaging to the environment), (5) general (applicable to different habitat types), (6) aids in distinguishing between natural processes and anthropogenic effects.

Additionally, certain *leading ecological indicators* that can be used to describe the health of the overall ecosystem to the public may be useful. These are analogous to *leading economic indicators* or certain crucial medical assays, such as body temperature or pulse. Ideally, these indicators would be ecologically relevant, scientifically defensible, economically significant, *and* have public appeal. However, this is not usually the case, so trade-offs may be necessary.

BOX 3: TOP-DOWN VS. BOTTOM-UP

Focusing exclusively on indicators at one hierarchical level of ecological organization has several disadvantages. For example, it has been suggested that the success of species at top trophic levels indicates the health of lower trophic levels. Organisms at top trophic levels, usually vertebrates, have often been used as indicators. Indicators of the status of "charismatic megafauna" serve useful functions, such as helping to maintain political will for restoration. However, because of their relative longevity, the actual causes of perceived declines, once detected, are often difficult to unravel (Laudenslayer 1991). For this reason, Landres et al. (1988) conclude that using vertebrates alone to indicate habitat quality for other species is not a sound method, and recommend the use of other indicators as part of a comprehensive monitoring strategy.

Monitoring at lower levels of organization within the ecosystem provides clues to the processes affecting the behavior of the whole (Rapport 1984) and may provide an early warning of ecological stress, because with this approach the ecological preconditions for a healthy ecosystem, such as primary productivity, are being monitored. Indicators of early steps in the process leading to stress are more useful in some ways than indicators which inform that the system is already ailing. For example, using indicator species associated with soil productivity (e.g., mycorrhizal fungi) quickly detects problems with processes that may be fundamental to the functioning of the system. Mycorrhizal fungi are important components in the diets of small mammals, which in turn are important diet components of carnivorous species (Laudenslayer 1991). In the case of eutrophication, monitoring nutrient inputs to the system may allow for early detection of an imminent problem, whereas monitoring of dissolved oxygen may signal changes only after it is too late for preventive measures.

Ultimately, when employing biota as indicators, a suite of indicators including multiple species and assemblages is more likely to provide improved detection capability over a broader range as well as protection to a larger segment of the ecosystem than single indicators (Kremen 1992; Karr 1993). As Noss (1990) states, "no single level of organization (e.g., gene, population, community) is fundamental, and different levels of resolution are appropriate for monitoring and protecting biodiversity." Thus, combining top-down and bottom-up approaches when developing indicators will produce the best suite of indicators.

IV. TYPOLOGY FOR THE BAY-DELTA-RIVER SYSTEM

Workshop participants agreed that indicators were needed at a variety of scales of ecological organization, such as the landscape, ecological zone, and habitat. A necessary preliminary step in the process is to develop a *habitat typology* (classification scheme) for the system, in order to clearly define the management units for which indicators should be selected.

In order to be useful, such a typology must reflect ecological realities (i.e., have a sound ecological basis) as well as address the needs of resource managers to clearly recognize management units, and relate them to one another. Another desirable trait of a habitat typology is broad applicability to other systems of its type, in this case large river ecosystems. Thus, wherever practical, the subunits of the typology should be recognizable in other similar systems. This allows for cross-reference of information gathered from a number of ecosystems (and/or their subunits), eventually allowing for the elucidation of common and unique attributes of similar ecosystems. This is especially valuable in the study of large complex ecosystems in which there exist many data gaps regarding the ecology of particular portions.

At the January workshop, participants were asked to consider and agree in plenary session upon the higher elements of the typology. This process was completed comparatively quickly, and with broad agreement. The system was first defined at the broadest (landscape/seascape) scale, and then subdivided into five *ecological zones* representing major biomes of which this system is comprised. The process resulted in the following scheme (see also Figure 5):

A. Level I: The Landscape/Seascape Level

The landscape/seascape encompasses the entire watersheds of the Sacramento and San Joaquin Rivers, their delta, San Francisco Bay, and the near shore ocean off the Golden Gate Bridge.

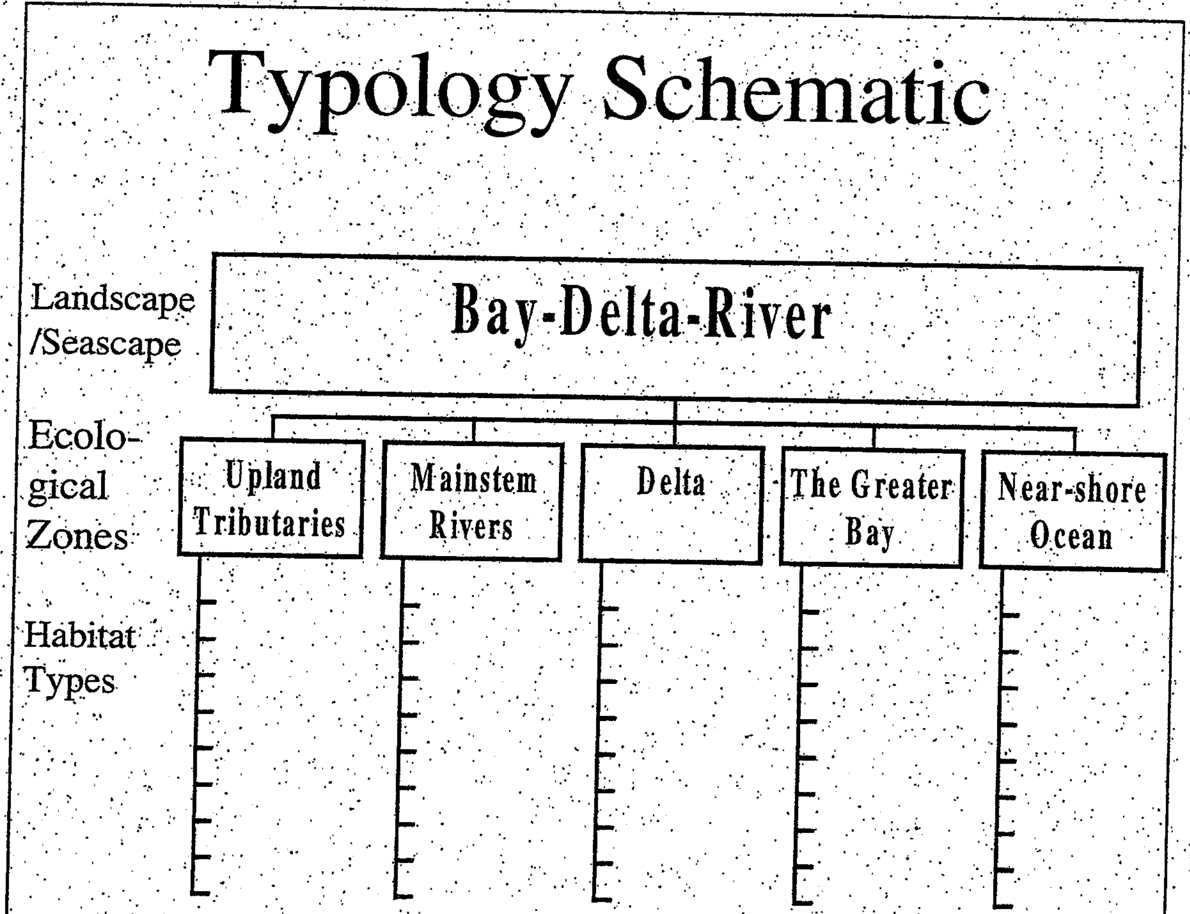


Figure 5: Schematic of the typology framework used for indicator development and organization, indicating the five ecological zones upon which workshop participants came to consensus. The habitat types are shown in Chapter IV.

B. Level II: Ecological Zones

- **Upland Tributaries & Watersheds**-- Includes headwaters to juncture with mainstem rivers.
- **Mainstem Rivers**-- The Sacramento and San Joaquin, above the tidal influence.
- **The Delta**-- This zone includes the tidally influenced portions of the two mainstem rivers. The Delta is delineated in the west by Chipps Island, in the north by the confluence of the Sacramento and American rivers, and in the south by Vernalis.
- **Greater San Francisco Bay**-- Extends roughly from Chipps Island to the Golden Gate Bridge. This zone includes Suisun Bay, San Pablo Bay, the Central Bay, and the South Bay.
- **Near-shore Ocean**-- A corridor extending 25 miles north and south of the Golden Gate Bridge, and seaward (west) to the continental shelf break.

At the workshop, there was some deliberation over how to split the Bay-Delta-River system into distinct ecological zones. Specifically, issues came up about whether the tidally influenced portions of the mainstem rivers were separable from the delta and whether Suisun Bay should be considered distinct from the rest of the Greater San Francisco Bay. Suisun Bay could be considered a portion of the Greater Bay or part of the Delta, since hydrological processes tie it more to one in wet years and more to the other in drier years.

Categorizing dynamic systems into different zones is inherently a somewhat arbitrary process, but one which facilitates discussion and management. In developing indicators, therefore, boundaries should not be adhered to strictly. When there is crossover between habitat types (e.g., tidal marshes exist in the delta and the bay) indicators can be aggregated across all zones which contain this type of habitat.

C. Level III: Habitat Types

Within each of the ecological zones, several discrete habitat types exist. Participants were asked to divide themselves, according to expertise and interests, into five groups corresponding to the five zones delineated above, and to take the typology to its next level, that of primary and, where appropriate, secondary habitat types.

Within each zone, primary habitat types were to be considered ecologically distinct areas (in terms of structure and vital ecological processes), supporting distinctive and characteristic biological communities. Secondary habitat types were to be subdivisions of the primary habitats that were felt to be distinctive enough to warrant separate consideration within the context of this project. Thus "unconsolidated sediments" might be considered a "primary" benthic habitat type for the nearshore ocean, but distinctive and systematic differences in the community structure of benthic invertebrates might warrant a distinction between "mud" and "sand" as secondary habitat types within this scheme. Because the primary objective of the project was to develop a broad perspective of the system at the landscape scale, participants were urged to use the secondary habitat category only when necessary, to keep the group from becoming involved in analyses that were too 'fine-grained' for the intended purposes of these workshops.

The results of the working groups for each zone are presented in their raw form, as reported and edited by the group leaders, in the minutes of the January workshop (Appendix B-5). Because the participants were of many different backgrounds and interpreted the basic guiding principles and directions in different ways, the final typologies derived by each group were reported in different, and in some cases incompatible, formats. In order to further the goal of a cohesive and integrated typology for the system with wide applicability to other large river systems, the technical staff of TBI and EDF modified the information provided by the breakout groups. Prior efforts to classify aquatic habitats in a variety of other ecosystems guided our efforts. The resulting typology (showing only the primary habitats) is presented in Table 1. Secondary habitats proposed by breakout groups are not reflected in this table, but are included in Appendix B-5.

Table 1: Expanded Habitat Typology for the Bay-Delta-River system. Water column, benthic, edge, and other habitats are given for each ecological zone.

	UPLAND TRIBUTARIES	MAINSTEM RIVERS[3]	DELTA	GREATER BAY	NEARSHORE OCEAN
Water Column Habitats	• Pools/riffles • Runs/glides	• Pools/riffles • Runs/glides	• Riverine • Flooded islands • Mixing zone • Sloughs	• Shallow (<? m) • Deep (>? m) • Mixing zone	• Marine • Freshwater plume
Benthic Habitats	• Unconsolidated -Gravel -Sand -Boulders	• Unconsolidated -Gravel -Sand -Mud	• Unconsolidated -Mud -Sand	• Unconsolidated -"unvegetated" -vegetated • Consolidated	• Unconsolidated • Rocky reef • Kelp beds
Edge Habitats	• Riparian • Floodplain	• Riparian • Floodplain	• Tidal marsh • Non-tidal marsh • Riparian • Floodplain	• Marine marsh • Brackish marsh • Freshwater marsh • Other vegetated • "Unvegetated" intertidal	• Rocky intertidal • Beach • Wetlands
Related Habitats				• Small streams • Managed marshes	• Offshore islands • Dunes

[3] Mainstem rivers can be further separated into three geomorphic divisions: an upstream reach, dominated by pools and riffles, a middle reach consisting of an active meander zone, and a lower reach being a low-gradient floodplain. For consistency among the ecological zones, these three reaches are combined here.

V. INDICATORS OF ECOSYSTEM HEALTH

At the January workshop, the discussion of landscape-level indicators was led by Charles Simenstad, of the University of Washington, in plenary. Indicators for each ecological zone and habitat type were developed in breakout group sessions. The breakout groups used a variety of formats to develop different sets of indicators.

Several groups organized their discussion and indicator development by listing objectives which they deemed necessary to achieve ecological health. There was a significant amount of overlap among the objectives proposed by the various groups, so we have consolidated them into a list of eight (see Table 2). These objectives encapsulate participants' best expression of what needs to be accomplished to achieve the overall goal for Bay-Delta-River restoration and management (see p.10). It is important to note that these eight objectives are not prioritized here. All must be achieved in order to support the system-wide goal stated above. We have attempted to relate each indicator or property assessed to these objectives.

In the matrices on the following pages, italics indicate that the item was composed by the EDF/TBI technical staff after the workshop in an attempt to provide a more complete and useful document that reflected common themes expressed during the workshops. Our additions are based upon notes from the workshop and our own interpretation of the indicators. Relevant objectives (by letter designation) are noted in the column titled "OBJ." The work done by each group, in its original format, is reported in the draft workshop minutes (see Appendix B-5).

Table 2: Restoration Objectives. Objectives A-H have been synthesized from objectives offered by the breakout groups at the January workshop. The groups' objectives are listed below each lettered objective.

A. Ensure conditions necessary to support and protect native biodiversity

- Biodiversity (landscape, delta)
- Increase naturally-produced populations of anadromous fish (NHI workshop)
- Restore populations of indigenous species to levels not likely to result in extinction (NHI workshop)

B. Protect and/or restore conditions necessary to increase populations of valuable plant and animal species (in a manner consistent with Objective A)

- Increase fish & wildlife (landscape)
- Survival, fitness, and condition (delta)
- Fish & wildlife species support (bay)
- Support of migratory species (bay)
- Restrict additional introductions of exotic species (NHI workshop)

C. Ensure sufficient extent, diversity, quality, connectivity, and range of successional states of natural habitats

- Movement (flow) of motile/migratory organisms (spp. of concern, prey) (landscape)
- Feeding opportunity (landscape)
- Aquatic and riparian habitat (rivers)
- Migration habitat (provided by SRA) (rivers)
- Connectivity between habitats (rivers)
- Fish habitat (rivers)
- Food supply for organisms (delta)
- Fish, bird (incl. nesting), mammal, invertebrate habitat (delta)
- Fish migration (delta)
- Habitat access (delta)
- Minimization of predation effects (delta)
- Fish and wildlife habitat (bay)
- Fish & macroinvertebrate habitat (bay)
- Supply of resident wildlife habitat (bay)
- Stabilize shorelines (landscape)
- Protection of shoreline from erosion (bay)
- Structural integrity of shoreline and benthic habitats (nearshore ocean)
- Maintain sediment contamination at least below levels seen in 1950 (NHI workshop)
- Sustain natural evolution of baylands (NHI workshop)
- Decrease turbidity of the water and increase seagrass habitat (NHI workshop)

D. Protect and/or restore the natural trophic structure of communities

- Food web support (landscape, bay)
- Food supply for organisms (delta)
- Food web support (trophic dynamics) (delta)

E. Protect and/or restore natural patterns of transport of essential materials (water, sediments, nutrients)

- Nutrient exchange (landscape)
- Maintain & restore habitats' sediment supply (landscape)
- Diverse sources, production, distribution of organic matter (landscape)
- Sediment supply (rivers)
- Biological filter/sediment trap/water quality (delta)
- Supply of organic matter (dissolved or particulate) (bay)
- Sediment supply (bay)
- Nutrient cycling (bay)

F. More closely approximate the natural hydrological regime

- [Based on indicators proposed by the Landscape and Rivers groups]

G. Protect and/or restore water quality

- Improve water quality (landscape)
- Biological filter/sediment trap/water quality (delta)
- Water quality/fish foraging (bay)
- Water quality (nearshore ocean)
- Prevent conditions that result in water column anoxia or nuisance algal blooms (NHI workshop)

H. Provide for societal uses (harvest, recreation, aesthetics)

- Aesthetics (delta)
- Human health (delta)
- Commercial & recreational fishery (bay)
- Shellfish harvest (bay)
- Sustainable harvest levels (nearshore ocean)
- Provide anglers with a reasonable chance of catching sport fish (NHI workshop)
- Enhance aesthetic values (NHI workshop)
- Maintain populations of fish and waterfowl that can be eaten safely (NHI workshop)
- Establish a viable commercial fishery in San Francisco Bay that provides fish or shellfish for consumption (NHI workshop)

Some groups followed the matrix for indicator development (Figure 4) more closely than others, so certain components of the framework are more complete for some groups. Because not all groups developed indicators at both the ecological zone and habitat type levels, and because the habitat types have been reorganized for consistency among groups (see Table 1), not all habitat types have indicators associated with them. However, it is important to note that this is a first cut at the suite of indicators; we need now to go back and fill in the holes and, to the extent necessary, refine the list. We have intentionally printed some sections of the matrices blank to show further work that could be done. Indicators being monitored by existing monitoring programs can be mapped on to the matrices to allow managers to look at the whole picture when evaluating their monitoring scheme and choosing what to measure.

Ranking indicators will be important to managers, and some groups began this process. Since not all of the groups went through this exercise, the rankings were not included in the final matrices (but they are recorded in the workshop minutes, Appendix B-5). Additionally, insufficient time was available at the workshop to conduct a systematic evaluation of the indicators to see if they meet the criteria for indicator development. Worksheets were provided for this purpose (see Appendix B-3) at the January workshop, and can be used in the future to further refine and help finalize the suite of indicators. Eventually, the suite of indicators for the Bay-Delta-River system should include information explaining the rationale for each indicator and also the methodology for measurement (e.g., aerial photography or surveys of user satisfaction). Examples of rationales for indicators can be found in the written submission provided by Matt Kondolf and Pete Chadwick, explaining each indicator suggested by the joint Rivers group (January workshop minutes, pp. 11-14, Appendix B-5).

A. Indicators at the Landscape-level

Landscape scale indicators integrate system-wide health measures and elucidate the connections and interworkings of various parts of the system. Indicators in all regions respond to landscape scale processes. For example, processes across the habitats respond to fluctuations in freshwater flow.

Charles Simenstad, in the discussion he led at the January workshop, suggested that indicators at the landscape-level should be: applicable across habitats, ecosystems, and zones; directly or indirectly a measure of principal forcing processes; capable (scientifically, feasibly) of detecting change; scaled across levels of landscape organization; and referenced to baseline or target/expected levels (that encompass natural variability or noise in the system). This plenary discussion resulted in the indicators shown below.

LANDSCAPE		
OBJ.	PROPERTY ASSESSED	INDICATOR
ALL	*S1. Landscape integrity*	• Sum ecological zone indicators across the landscape (% of elements)
A, B, C	*S2. Habitat quality*	• Natural channel density and complexity
A, B, C, D	*S3. Habitat diversity*	• Proportional representation and area of all habitats
A, B, C, E, H	S4. Connectivity of habitats (corridors)	• Distance between interacting habitat types ("feeding stations") • Average distance between nesting and foraging habitats for (resident) birds • Total number of temperature/physiochemical barriers to salmon migration • Number of barriers/bottlenecks to movement of motile/migratory organisms
C, E, F, G	F1. Natural water flow regime	• Variability in flooding duration and frequency
C, D, E, G	*F2. Natural sedimentation regime*	• Sediment flux and distribution • Sediment delivery to the estuary
A, B, D, E	F3. Total landscape productivity	
		• Morphometry of the estuary (related to tidal prism)

B. Indicators for Each Ecological Zone and Habitat Type

MAINSTEM RIVERS & UPLAND TRIBUTARIES[4]

Group participants:

1. Pete Chadwick (moderator)
2. Matt Kondolf (moderator)
3. Sharon Gross
4. Judy Kelly
5. Bill Kier
6. Bruce McWilliams
7. Jud Monroe
8. Tim Ramirez

ECOLOGICAL ZONE: Rivers		
OBJ.	PROPERTY ASSESSED	INDICATOR
A, B, C	*S1. Extent and quality of edge habitat*	• Channel length (including side channels) • Ratio of current : historical channel length • Length of SRA[5] bank • Length of rip-rap bank • Areal extent of classes of riparian vegetation
A, B, C, G, H	*S2. Quality of anadromous fish habitat*	• Abundance of adult anadromous fish • Survival rate of outmigrant anadromous fish • Number of outmigrants by race
C	*S3. Potential extent of aquatic habitat*	• Areal extent of open sand/gravel-floored channel
A, B, C, F	*S4. Extent of floodplain* *S5. Connectivity of habitats*	• Area flooded by 2 year and 10 year floods
A, B, C, F	*S6. Sufficiency of meander belt* *S7. Habitat diversity*	• Area (width) of potential meander belt migration • Channel migration rate
C, G, H	**S8.** Water quality	• Water temperature • Dissolved oxygen • Concentrations of toxic substances
C, E, F, G	**F1.** Deviation from natural hydrograph	• Floods: post dam/pre-dam: Q_{maf} Q_2, Q_{10}, Q_{20} • Baseflows: post/pre-dam: Q_{av}, August, Sept., ? • Spring outflows: post/pre-dam: Q_{av}, May, June, July
A, B, C, E, F, H	*F2. Natural transport of organisms*	• Number of unscreened diversions
E	**F3.** Deviation from natural sediment budget	• Percentage of pre-dam supply of gravel & sand-sized sediment delivered to the reach
E, G	**F4.** Groundwater regime	

[4] Due to considerations at the workshop relating to the size of breakout groups, the ecological zones *Mainstem Rivers* and *Upland Tributaries* were merged for the purposes of the workshop and this report. Nevertheless, these two ecological zones should still be regarded as distinct.

[5] Shaded Riparian Aquatic habitat

DELTA

Group participants:

1. Bruce Herbold (moderator)
2. Eli Ateljevich
3. David Behar
4. Patrick Coulston
5. Phyllis Fox
6. David Fullerton
7. Chuck Hanson
8. Rick Soehren
9. Phil Williams
10. Leo Winternitz

ECOLOGICAL ZONE: Delta

OBJ.	PROPERTY ASSESSED	INDICATOR
A, B, C, G, H	*S1. Quality of anadromous fish habitat*	• Smolt survival through zone
B, C, G, H	*S2. Water quality*	• Water toxicity • Number of exceedences of water quality standards per year • Harvest levels of non-toxic fish
A, B, D	*S3. Exotic species*	• Number of introduced species of fish and invertebrates per year
A, B, C	S4. Dispersal of estuarine species and landscape geographical distribution	• Population levels of desirable species • Index of native species abundance
A, B, D	S5. Stability of community structure	• Rank abundance
C, E, F, G	*F1. Deviation from natural hydrograph*	• Percent of inflow diverted
A, B, H	*F2. Fish entrainment and total diversions*	• Total number of diversions • Ratio of screened/unscreened diversions
F, H	F3. Flood risk	• Amount of susceptible agricultural lands taken out of production
H	*F4. Quality of recreation*	• Degree of user satisfaction (measured by surveys) • Non-consumptive recreation hours
A, B, D	F5. Primary and secondary productivity	
		• Total sediment accumulation/ marsh accumulation

	HABITAT TYPE: Water Column-Riverine		
	OBJ.	PROPERTY ASSESSED	INDICATOR
Community/ Ecosystem	A, B, C, D	*S1. Extent of edge habitat*	• Area or length of berm islands
	A, B, C	*S2. Extent of dead-end slough habitat*	• Length of dead-end slough
	A, B, C, D	*S3. Habitat quality*	• Ratio of degraded to high quality (such as SRA[5]) bank habitat
	A, B, C, D, E	*S4. Connectivity of habitats*	• Area of connected emergent vegetation (tidally influenced)
	C, D, G, H	*S5. Water quality*	• # of applications of toxic materials (e.g., pesticides) • % of sport fish of legal size that have unacceptable toxin levels
	A, B, C, H	F1. Fish entrainment (and) total diversions	• Number of barriers to fish passage; fish migration • Number of unscreened diversions
	A, B, E, F	*F2. Favorable migration flows*	• Net positive flows during migration
Population/ Species	A, B, H	*S6. Fish abundance*	• Fish counts

***Note: words in parentheses signify secondary or tertiary habitat types

	HABITAT TYPE: Water Column-Flooded Islands		
	OBJ.	PROPERTY ASSESSED	INDICATOR
Community/ Ecosystem	A, B, C	*S1. Habitat quality and extent*	• Area and linear edge of emergent vegetation • Diversity and stature of emergent vegetation
Population/ Species			

HABITAT TYPE: Water Column-Sloughs

	OBJ.	PROPERTY ASSESSED	INDICATOR
Community/ Ecosystem	A, B, C	*S1. Habitat extent*	• Length of dead-end slough • Number of branches
Population/ Species			

HABITAT TYPE: Edge-Tidal Marsh

	OBJ.	PROPERTY ASSESSED	INDICATOR
Community/ Ecosystem	A, B, C	*S1. Habitat quality and extent*	• Quantity (area) of marshes with median marsh size above a certain threshold intertidal marsh • Area of evolved marshland (large marsh in which channels develop at a minimum rate) • Area of evolved marshland with buffer (at least certain distance from agricultural or urban areas)
Population/ Species			

HABITAT TYPE: Edge-Nontidal Marsh

	OBJ.	PROPERTY ASSESSED	INDICATOR
Community/ Ecosystem	C, H	*S1. Extent of shallow agricultural lands*	• Area of land less than one foot deep in December or March
	A, B, C	*S2. Extent of vernal pools*	• Area of natural vernal pools protected
	A, B, C	*S3. Extent of upland habitat*	• Length and width of riparian forest (riparian not adjacent to water)
	A, B, D.	F1. Amount of food (Kcal) produced which is available to waterfowl (may be separated by source into agricultural spoils and natural production)	
Population/ Species			

HABITAT TYPE: Edge-Riparian

	OBJ.	PROPERTY ASSESSED	INDICATOR
Community/ Ecosystem	A, B, C, D, E	*S1. Habitat extent*	• Length and width of riparian forest (riparian not adjacent to water) • Area or length of berm islands
	A, B, C, D, H	*S2. Habitat quality*	• Ratio of degraded to high quality (such as SRA[5]) bank habitat
Population/ Species			

HABITAT TYPE: Edge-Floodplain

	OBJ.	PROPERTY ASSESSED	INDICATOR
Community/ Ecosystem	A, B, C, D, H	*S1. Extent of upland habitat*	• Length and width of riparian forest
	A, B, C, E, F	S2. Sufficiency of meander belt	• Width of active meander belt
	A, B, C, E, F	*S3. Connectivity of habitats* *F1. Natural water flow regime*	• Area of two/other-year frequency floodplain that interacts with river floodplain
Population/ Species			

GREATER SAN FRANCISCO BAY

Group participants:

1. Fred Nichols (moderator)
2. Roberta Borgonova
3. Randy Brown
4. Josh Collins
5. Susan Hatfield
6. Alex Horne
7. Lee Lehman
8. Charles (Si) Simenstad

ECOLOGICAL ZONE: The Greater Bay

OBJ.	PROPERTY ASSESSED	INDICATOR
A, B, C	*S1. Habitat extent*	• Habitat acreage
A, B, C	*S2. Habitat quality*	• Channel density
A, B, C, E	**S3**. Connectivity of habitats (at several scales)	
C, G, H	*S4. Water quality*	• Salinity • Pollutant concentrations • Distribution of pollutants
A, B, D	*S5. Exotic species*	• Number and/or biomass of newly introduced species
C	**S6**. Complexity of elevational structure (topographic complexity)	
C	**S7**. Vegetative patch structure	
C, E	**S8**. Distribution of subordinate estuaries	
A, B, C, D, G	**F1**. Capacity to support resident fish & wildlife	• Habitat acreage
E, F, G	**F2**. Freshwater flow variations	
A, B, C, D, E	*F3. Contribution of marshes to food web of the Bay*	• Amount of marsh-derived organic material in bay organisms
D, G	**F4**. Sediment supply	
A, B, H	**F5**. Residence time of juvenile anadromous fish	
C, E	**F6**. Net transport of organic matter at habitat interfaces	

HABITAT TYPE: Water Column-Shallow

	OBJ.	PROPERTY ASSESSED	INDICATOR
Community/ Ecosystem	A, B, D	*F1. Food web support*	• Water column stratification • Diatom : flagellate ratio • Biomass of planktivorous fish
	A, B, D	F2. Primary production	• Chlorophyll *a* • Turbidity
	A, B, H	*F3. Fishery support*	• Catch per unit effort
Population/ Species	A, B, C, D, H	*S1. Fish and wildlife abundance*	• Density and diversity of larval fish • Diving bird abundance and diversity • Harbor seal abundance
	A, B, D	*F4. Secondary production (?)*	• Juvenile herring growth rate

HABITAT TYPE: Water Column-Deep

	OBJ.	PROPERTY ASSESSED	INDICATOR
Community/ Ecosystem	A, B, D	*F1. Food web support*	• Benthic shrimp & mysid biomass/density • Mollusc biomass/density
	C, G	*F2. Water/sediment quality*	• Change in pollutant levels in sediments
Population/ Species			

HABITAT TYPE: Water Column-Mixing Zone

	OBJ.	PROPERTY ASSESSED	INDICATOR
Community/ Ecosystem	A, B, C	*S1. Extent of habitat*	• X_2 • Exceedence of X_2
Population/ Species			

HABITAT TYPE:Benthic-Unconsolidated-"Unvegetated"

	OBJ.	PROPERTY ASSESSED	INDICATOR
Community/ Ecosystem	A, B, D	*F1. Food web support*	• Benthic shrimp & mysid biomass/density • Mollusc biomass/density
	C, G	*F2. Water/sediment quality*	• Change in pollutant levels in sediments
Population/ Species			

HABITAT TYPE:Benthic-Unconsolidated-Vegetated

	OBJ.	PROPERTY ASSESSED	INDICATOR
Community/ Ecosystem	A, B, C	*S1. Habitat extent*	• Acreage
	A, B, C	S2. Macroalgae and SAV coverage	
Population/ Species	A, B, D	S3. Support of herring spawning	• Density of herring eggs
	A, B, C, D	*F1. SAV and macroalgae health*	• Epiphyte load
			• Seagrass shoot density

HABITAT TYPE:Benthic-Consolidated Substrate

	OBJ.	PROPERTY ASSESSED	INDICATOR
Community/ Ecosystem	A, B, C	*S1. Habitat extent*	• Amount of natural hard substrate
Population/ Species	A, B, C, D	S2. Support of herring spawning	• Density of herring eggs • Proximity to "holding areas"

	HABITAT TYPE:Edge-Marshes (Salt, Brackish, & Freshwater)		
	OBJ.	PROPERTY ASSESSED	INDICATOR
Community/ Ecosystem	A, B, C	*S1. Habitat extent*	• Acreage
	A, B, C	*S2. Habitat quality*	• Habitat metrics for each ecologically important species (e.g., marsh plant density) • Channel density • Diversity of plant species • Ratio of non-vegetated : vegetated marsh
	C, G, H	*S3. Water quality*	• Pollutant concentrations
	C	**S4.** Complexity of elevational structure (topographic complexity)	
	C	*F1. Shoreline stability*	• Change in position of marsh edge (towards shoreline (-); away from shoreline (+))
	A, B, C, D, E	*F2. Contribution of marsh to food web of the Bay*	• Amount of marsh-derived organic material in bay organisms
	E, G	F3. Sedimentation rate	
	C, E	F4. Net transport of organic matter at habitat interfaces	
			• Width of marsh relative to wave energy (fetch and boat wakes)
Population/ Species	A, B, D	*S5. Exotic species*	• Proportion of *Spartina alterniflora* in the marsh community
	A, B, C, H	*S6. Abundance of important species*	• Change in population of ecologically important species

	HABITAT TYPE:Edge-"Unvegetated" Intertidal		
	OBJ.	PROPERTY ASSESSED	INDICATOR
Community/ Ecosystem	A, B, C	*S1. Habitat extent*	• Acreage
	A, B, C, E	*S2. Habitat quality*	• Deviation from expected elevation
	A, B, D	S3. Prey abundance & distribution	
	A, B, H	F1. Fishery success rate	• *Catch per unit effort*
	A, B, D	*F2. Productivity*	• Chlorophyll *a* on sediments
Population/ Species	A, B, C	*S4. Wildlife abundance*	• Wildlife sign (incl. bird feces, bat-ray divets)- rate/time

	HABITAT TYPE: Related Habitats-Small Tributary Streams		
	OBJ.	PROPERTY ASSESSED	INDICATOR
Community/ Ecosystem	A, B, C	*S1. Extent of brackish habitat*	• Area of brackish water habitat at stream mouths
	A, B, C, E, F	*S2. Connectivity of habitats*	• Number of "barriers" to fish passage • Number of young, outmigrating anadromous salmonids
Population/ Species			

	HABITAT TYPE: Related Habitats-Managed Marshes		
	OBJ.	PROPERTY ASSESSED	INDICATOR
Community/ Ecosystem	A, B, C	*S1. Habitat extent*	• Acreage
	A, B, C	**S2.** Habitat quality	• Diversity of plant species
	A, B, C, E, F	**S3.** Connectivity to natural habitats	• Proximity to & amount of neighboring sanctuaries and natural habitats
	A, B, C	**S4.** Habitat complexity	
	C, F, G, H	**F1.** Water quality/supply	
Population/ Species			

NEAR-SHORE OCEAN

Group participants:

1. Bill Alevizon (moderator)
2. Rod Fujita (moderator)
3. Bill Kier
4. Ann Nothoff

ECOLOGICAL ZONE: Near-Shore Ocean

OBJ.	PROPERTY ASSESSED	INDICATOR
A, B, C, D	**S1.** Habitat quality	• Stability of community structures in each primary habitat type
A, B, C	**S2.** Habitat extent and diversity	• Total area and proportionate amount of primary habitat types
A, B, C, G, H	**S3.** Water quality	• Toxic levels in birds, fish, others • Average turbidity (landsat)
C, F	**F1.** Water project effects	• Vertical salinity profile • Sedimentation rates, by type and amount • Nutrient (nitrate/phosphate) levels relative to average levels from adjacent areas of ocean
A, B, D	**F2.** Production	• Average chlorophyll levels (landsat)
A, B, C, H	**F3.** Fishery support	• Catch/unit effort of harvestable fish

***Note: It was recommended that substantially more work would need to be done to identify suitable indicators for this ecological zone .

VI. USING INDICATORS TO RESTORE ECOSYSTEM HEALTH

A. Where Do We Go From Here?

The indicators derived at the January workshop provide a solid starting point for full development of a suite of indicators for the Bay-Delta-River system. The next stage of the process will involve refining this suite of indicators. Using the framework, typology, and preliminary suite of indicators developed through this project, each component of the typology can be addressed and refined in turn. A separate group of experts for each of the different components of the typology, capitalizing on the expertise in existing programs, may be the most appropriate forum for indicator refinement. At this stage, we anticipate that monitoring being done by existing programs will be added to the matrices.

Eventually, the suite of indicators should indicate, for each indicator, the objective it relates to, the exact property which it assesses, the rationale explaining why it is a useful measure, and the methodology for measuring it in the field.

Once the suite of indicators is refined, ranges of target values can be set for each indicator (Step 3). These thresholds will be the real tool for on-the-ground management and monitoring (Step 4). Long-term monitoring and baseline information upon which threshold values are set will be based on research organized around the indicators and other specific hypotheses. Previous work by existing monitoring programs will be useful in providing historical databases.

B. How the Indicators Can be Used

Planning, Monitoring and Evaluating Restoration Efforts

When used to guide restoration actions, indicators can be divided into categories of *diagnostic* and *prescriptive*. The former informs managers of the problems in the

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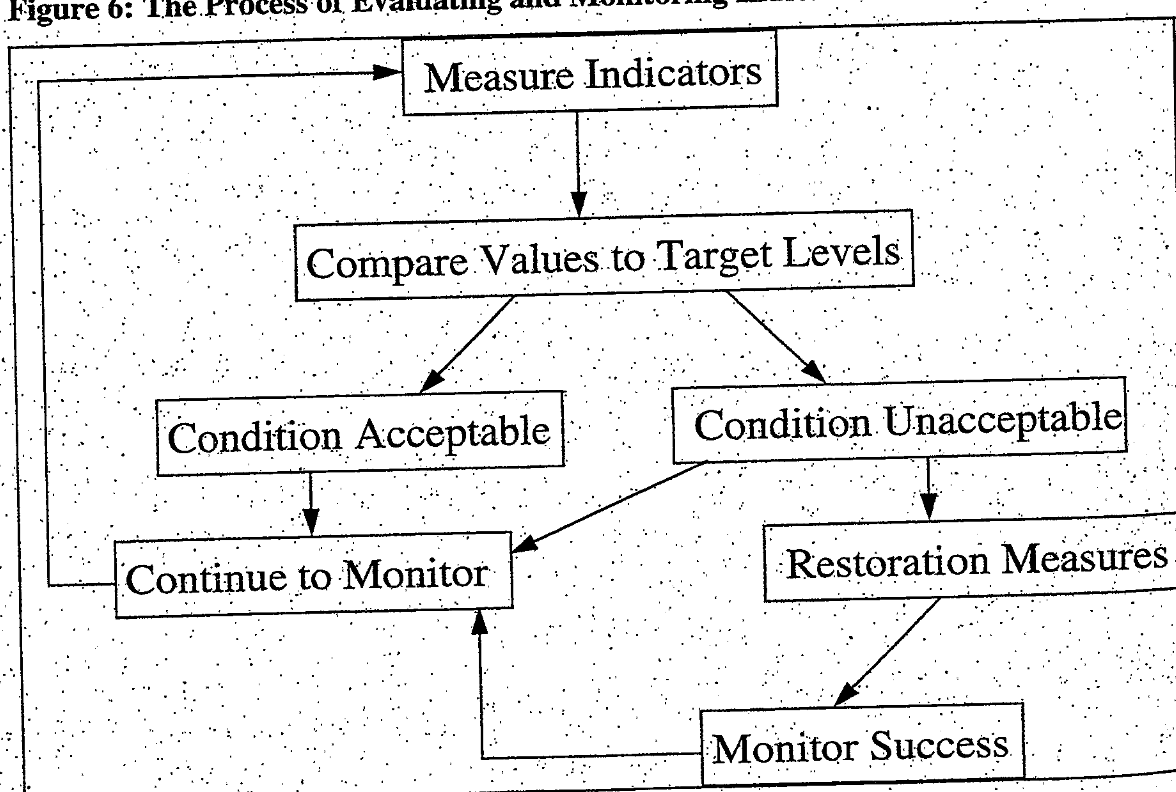
system and the latter indicates what can be done to correct it. Diagnostic indicators are by definition not open to manipulation, while prescriptive indicators are linked to ecosystem processes that could in fact be manipulated and managed. Thus, diagnostic indicators assess achievement of goals and prescriptive indicators provide guidance for managers on what to do to achieve the goals.

Any restoration measures taken in the Bay-Delta-River system will require extensive monitoring. Indicators can be used to focus the monitoring effort on the most relevant and useful parameters, and to evaluate the attainment of restoration goals and objectives. Because few precedents exist for restoration in large-scale systems, careful evaluation of the results will be invaluable both for this and other systems.

Adaptive Management

The threshold values for the indicators will provide the basis for an adaptive management program, by which management actions, indicators and thresholds are evaluated and adjusted as necessary (see Figure 6).

Figure 6: The Process of Evaluating and Monitoring Indicators



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Public Accountability

Monitoring of indicators will be critical in relating Bay-Delta-River information to the public. Public interest and enthusiasm for large-scale projects depend on effective communication among scientists, policy makers, government agents, the media, and the public. Conversely, responsible management depends on accountability to the public. One effective mode of communication might be to develop a list of the ***leading ecological indicators*** for the system, which could be published regularly by the media. Examples of these kinds of indicators might include salmon abundance or area of wetlands restored. Five or so such leading indicators could be developed by a small steering group of policy makers and scientists, then subjected to external peer review.

Establishment of an Ecological Health Board

One suggestion brought up at the workshops was the establishment of an **Ecological Health Board**, which would use the information generated by monitoring efforts to indicate where restoration efforts are working, where we need better ecosystem health, and what other parameters or regions need to be monitored. The board would need to be vested with substantial authority to maintain or modify management measures in accordance with lessons learned from the indicators and related research.

Influencing Policy

In terms of the current Bay-Delta-River events, the two immediate applications of the indicators are to help evaluate the CalFed alternatives and the Anadromous Fish Restoration Plan (AFRP). The indicators can be used in ongoing evaluations of the AFRP and other plans, as well as in future versions of the CalFed alternatives and in the NEPA/CEQA process with which CalFed will be involved later this year. In his closing remarks at the January workshop, Dick Daniel, CalFed Assistant Director for Habitat Restoration, said that the results of the workshop will influence the CalFed planning process in validating and refining actions and components of the alternatives, helping to set priorities, guiding the necessary near and longer term research, and helping to develop a vision for restoration of the landscape and for the ecological zones. The ultimate purpose of the indicators, according to Daniel, will be to eventually measure the successes of the program.

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PAPERS SUBMITTED BY WORKSHOP SPEAKERS

OBSERVATIONS ON CHOOSING INDICATORS OF ECOLOGICAL INTEGRITY

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Criteria of Landscape Indicators

Because the processes that shape and maintain estuarine habitats are manifested across strong environmental gradients, ecological integrity of estuarine habitats depends extensively upon their setting in a broader landscape continuum. Water flow, tidal flooding and exposure, mixing with saltwater, sediment deposition and erosion, nutrient recycling, and basic energy levels (e.g., turbulence) are some of the more important factors (among others) that form gradients aligned across the estuarine landscape. As these gradients are usually the result of interacting forces or constituents, the gradients are typically non-linear. Ecological responses to these gradients by organisms are also complex because more than one gradient is usually involved. Thus, the "functions" provided by any one ecosystem component (i.e., habitat) are strongly influenced by multiple external driving forces that are a factor of both the position along the gradient and the relationships to other components structured across the estuarine landscape. Indicators of ecological "integrity" (herein I refer to integrity as the overlap of function and structure) must, therefore, incorporate measures or metrics that assess these exogenous influences equal to endogenous indicators more typically assessed.

While some landscape-based criteria of ecological integrity have been developed for terrestrial landscapes, few if any have emerged for land-margin landscapes such as estuaries. Therefore, while there are no readily-available templates of landscape-based indicators that can be applied to evaluating restoration in San Francisco Bay-Sacramento/San Joaquin rivers delta, we can identify landscape-based *criteria* for identifying appropriate indicators of ecological integrity:

- Applicability across habitats, ecosystems and landscape: Preferably, indicators should be relatively scale independent and capable of assessing ecological "performance" at any level of landscape organization.
- Directly or indirectly assesses physicochemical forcing processes: The fundamental processes driving ecological responses in estuarine communities tend to be physical, geochemical or other abiotic "forcing" factors; indicators that incorporate the relationship between these forcing factors and the appropriate biotic response variable(s) would provide not only the means to make testable predictions about responses of indicator organisms to restoration manipulations, but would also provide potential design criteria.
- Scientifically and feasibly capable of detecting change: Indicators need to be sensitive enough to rapidly demonstrate a system-wide response to a change (e.g., restoration action) but not vulnerable to the ambiguities inherent in a low signal-to-noise ratio.
- Referable to baseline or target/expected levels of function: Indicator responses to restoration and other treatments much be distinguishable from natural variability over space or time.
- Integrative of landscape processes: Given the multitude of interacting factors (e.g., environmental gradients) that control ecological structure and processes in estuaries, indicators that faithfully integrate multiple forcing factors (rather than being sensitive to single ones) would provide better long-term prognoses of ecosystem condition.

Linking Landscape Structure to Ecological Function, Processes and Value/Services

Given the state of our scientific understanding about the relationship between landscape structure and ecological function among estuarine and other coastal habitats, it is imperative that, like restoration itself, indicators of ecological integrity be viewed as adaptive and evolving. Therefore, research and monitoring of restoration will have to necessarily assess a suite of potential indicators before being refined and modified with successive results. Such adaptive monitoring must include three linked components: (1) landscape structure; (2) ecological function

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or physicochemical or ecological processes that are involved in shaping and responding to the landscape structure; and (3) the socioeconomic services and values that constitute our anthropogenic measure of restoration success. The first and second components are obviously highly interrelated, as landscape structure both generates and is a consequence of large-scale processes. An important aspect of assessing these interactions is to adequately encompass the total scale in which they occur in both space and time. For instance, sedimentation that promotes and maintains emergent marshes in estuaries is dependent upon both distant sources and the hydrodynamic mechanisms of transport between the source and the estuarine site. Measuring sediment accretion or erosion at a site will not necessarily be indicative of the long-term stability of a site's geomorphic features that are important to a socioeconomic service, e.g., fish and wildlife use of tidal channels. Similarly, the effect of interannual and even decadal events in imposing a pulse of sediment or erosion may ultimately need to be evaluated before the long-term variability in a site's landscape structure can be appreciated.

Furthermore, the complex trade-offs inherent in making socioeconomic decisions about restoration requires a comprehensive view of interactions between desirable ecological values and services and large-scale processes and landscapes. Where fragmented landscape elements (e.g., highly developed shorelines disbursed among estuarine marshes and beaches) along distributary channels may impose barriers and bottlenecks to some species (e.g., fish migrating along shallow shoreline habitats), the exact same landscape structure may provide a refuge for other species. Marsh area may constitute a direct indicator of emergent vegetation primary production contributing to the detritus-based estuarine food web far removed from the marsh site, but may not be an appropriate indicator of nutrient exchange because tidal channel geomorphology is affected by entirely different processes. Optimally, indicators that constitute "composite," overlapping measures of numerous processes, values and services will evolve from research and monitoring dedicated to understanding what forms and maintains landscape structure.

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DEVELOPING INDICATORS FOR ECOSYSTEM MANAGEMENT AND RESTORATION

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Indicators provide us with essential feedback on the state of our ecosystems and our biosphere. In the absence of indicators, we are blind. Moreover, debates about environmental policies are frustrated by both vagueness and excessive detail. Indicators provide us with a common frame of reference on which to base environmental decisions. More importantly, they provide a means to determine whether our decisions and actions lead to real changes in our life support system.

Choosing indicators would be easy if we had an exact body of science to tell us which components of our biosphere we must monitor. The science of ecology is still too young for this. But to borrow an analogy from automobiles, we generally agree that gauges for fuel level, engine temperature and speed are essential. Gauges for engine rotation speed and cabin temperature are optional. There are no gauges for ash tray fullness and floor dirtiness. Such practical decisions did not require endless scientific conferences and international treaties. Our challenge is to reach the same consensus about environmental indicators.

This challenge requires us to go through four, or perhaps only three steps. (In fact, with the benefit of hindsight, the first one, perhaps the most difficult conceptually and politically, may be not only optional, but best avoided). This first step is to (1) define health or integrity of ecosystems in an operational way. We do not want to get trapped in endless debates about what is healthy and what is not. However if we can agree upon what is undesirable, or what is a symptom of ecosystem sickness, then we might use the same characteristics to define health. In practice, it may be better to begin with (2), selecting the indicators themselves. Even if there is a disagreement about what exactly a healthy ecosystem is, we can surely agree in principle upon the main elements we ought to measure to help measure its performance. Here there are two sets of ecological variables to choose from. We can choose variables that describe the biological state of ecosystems; these might include primary productivity, biomass, diversity and life forms. We could also choose to measure the environmental factors that constrain and produce the biological variables; these might include factors such as flooding frequency, fire frequency, nutrient availability or salinity. (3) Identifying the target levels for each of these indicators then allows us to specify those situations which are desirable, and those which are not. By setting such target levels, we end up with an operational definition of our desired state of health; this achieves step 1 without risk of lengthy philosophical tangents. Finally, (4) we have to monitor our indicators to evaluate the performance of both the indicators and our policies. We are particularly interested in changes in response to management decisions. For example, if we spend so many millions of dollars trying to restore a wetland, it is quite reasonable to ask whether the expenditure really produces a measurable change in target indicators. If not, we should either question our indicators, or else look for another management tool that works.

More must be said about step 2. In general, we should start with the most important factors first. Then if time and energy permit, we can move to luxuries. With respect to biological properties, primary production and decomposition are obvious starting points, since they are fundamental properties measuring the way in which sun light is trapped and stored in ecosystems. Measures of biological diversity then tell us how the energy is allocated among different groups of organisms. If certain organisms are economically important, then these can be monitored as well. A similar logical order exists for exploring environmental factors. For example, in wetlands, hydrology probably accounts for some 50 percent of the variation in ecology, followed by fertility and salinity, each of which probably account for a further 20 percent. This would mean that all other factors, such as fire and grazing, account for only a further 10 percent. In wetlands it is therefore logical to begin by monitoring hydrological factors, fertility, and salinity. With care, it is possible that a set of indicator representing these three factors could account for at least three quarters of the variation in key ecological processes.

We should strive for simplicity and efficiency in our choices. This means that in general, we should select indicators that measure big important factors rather than local and trivial ones. Similarly,

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indicators based upon functional groups of organisms are preferable to abundance of a single species, or a small group of species. It seems that humans have an unfortunate tendency to favor specific detail over broad generality, and so special care must be taken to select macroindicators that address large temporal and spatial scales. In wetlands these might include catchment basin properties such as vegetation cover, area of pavement, and human population density. Finally, and perhaps most importantly, we can aspire to adopt similar indicators across the country and around the world. This will provide a common ecological currency for discussing problems and solutions, and may provide the foundation for global indicators.

In the long term, we can look forward to regularly reported indicators that allow us to judge progress. If we do our job properly now, we may put to rest some of our bleaker fears for the future, and simultaneously convince those who still deny that we are on a collision course with biological realty. Even as we argue over who should have the helm, and what course we should set, we can surely agree upon the need for an instrument panel to guide us.

KISSIMMEE RIVER RESTORATION PROJECT

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The Kissimmee River basin was once part of a vast, contiguous wetland system that extended from central Florida south to Florida Bay. The Kissimmee River basin included 26 headwater lakes ranging in size from a few hectares to 145 km^2 and the meandering Kissimmee River which originated at the southern end of Lake Kissimmee and flowed in southerly direction for approximately 166 km through a 1.5 - 3 km wide floodplain before emptying into Lake Okeechobee, the second largest (1730 km^2) lake in the conterminous United States. The historical Everglades originated as overflow from the southern end of Lake Okeechobee and formed a 100 km wide, 10,000 km^2 "river of grass" which dominated the south Florida landscape. The river, lakes and wetlands of the Kissimmee-Okeechobee-Everglades basin were a haven for fish and wildlife, including large flocks of wading birds, overwintering waterfowl and a nationally recognized, centarchid-based sport fishery.

During the last half century the physical configuration, hydrology and ecology of the Kissimmee-Okeechobee-Everglades system was greatly altered. As a result of the central and southern Florida flood control project, the system is now highly compartmentalized with a network of canals, levees and water control structures that are used to manage water levels and flow within and between each basin.

The Kissimmee basin portion of the flood control project was constructed between 1962 - 1971. The upper basin lakes were connected by canals and divided into a series of water storage reservoirs with dam-like water control schedules and operation rules. The Kissimmee River and floodplain were channelized to provide an outlet canal (C-38) for draining floodwaters from the upper basin watershed. As in the upper basin, water control structures divide the channelized river into a series of pools with stepped water surface profiles.

The flood control project had a devastating impact on the environmental resources of the Kissimmee basin. In the upper basin, lowered lake stages eliminated the outer fringe of littoral wetlands while the reduced range of water level fluctuations led to degradation of fish and wildlife habitats. The transformation of the river/floodplain ecosystem into a series of impoundments drained approximately two-thirds of the floodplain wetlands, largely eliminated wading bird and waterfowl populations, and led to a continuing long-term decline in game fish resources, particularly the largemouth bass fishery.

The broad array of environmental impacts provided the fuel for a persistent restoration initiative which began shortly after the flood control project was completed and focused on the channelized river and floodplain. The restoration movement led to several state and federal restoration mandates and provided the impetus for many restoration-related studies. Although analyses of restoration alternatives began in the early 70's, the restoration planning and evaluation process was impeded by a history of somewhat vague and subjective environmental objectives which were viewed and assessed independently. Proposed restoration measures targeted select resource values such as wading birds, waterfowl and wetlands, or functions such as nutrient and sediment filtration processes, as independent objectives. In fact, due to traditional and sometimes conflicting resource management interests of federal and state agencies, there was a constant risk of division among the biologists who were among the foremost restoration proponents.

Restoration planning reached a pivotal point in 1988 when a symposium was organized to establish environmental criteria for evaluating alternative restoration plans. The key outcome of this symposium was the adoption of a holistic restoration goal of reestablishing the ecological integrity of the river/floodplain ecosystem. The establishment of this goal effectively shifted the focus of restoration planning to the ecological factors and processes that maintained the structure and function of the historic ecosystem - the organizational and self-sustaining determinants of ecological integrity. Based upon the restoration initiative's long history of scientific studies, the major source of impact to ecological integrity in the channelized system was the alteration of the physical form and hydrology of the ecosystem. Accordingly, an integrated set of physical form guidelines and hydrologic criteria were developed from historical records and used in rigorous evaluations of restoration alternatives. Although the restoration movement focused on the channelized river, impacts of the flood control project on discharge characteristics of the headwater basin required that the hydrologic criteria embody a watershed perspective. The validity of using historically based guidelines and criteria for developing a plan for restoring ecological integrity was verified by a field demonstration project which confirmed the feasibility of restoring both the structure and function and the Kissimmee River ecosystem.

In 1990 the state of Florida adopted a restoration plan which will dechannelize the central portion of the system by filling 35 km of the flood control canal, removing two water control structures, and recarving 14 km of obliterated river channel. The restoration plan also includes modifications to the flood control regulation schedule for the river's headwater lakes, which will reestablish historic stage and discharge characteristics in the basin. This restoration plan is expected to restore the ecological integrity of 104 km^2 of river/floodplain ecosystem, including 70 km of contiguous river channel and 11,000 ha of floodplain wetlands. Over 2200 ha of littoral wetlands will be reestablished in the headwater lakes. The project will restore habitat for over 320 fish and wildlife species including the endangered wood stork, bald eagle and snail kite.

The Kissimmee River restoration project includes a comprehensive evaluation program which is designed to evaluate the success of the project in restoring ecological integrity. The evaluation program includes a broad range of ecosystem components, such as plant, invertebrate, fish and avian communities, ecological processes and functions, and a variety of habitat parameters. The program includes over 100 prioritized evaluation metrics and a six phase implementation framework.

LESSONS FROM "A SCIENTIFIC ASSESSMENT OF COASTAL WETLAND LOSS, RESTORATION AND MANAGEMENT IN LOUISIANA"

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In 1993-1994, I participated in a scientific assessment of coastal wetland loss, restoration and management in Louisiana as a member in a panel of environmental scientists external to Louisiana with expertise in the science and engineering of coastal wetlands. This independent evaluation was sponsored by the W. Alton Jones Foundation, and was specifically addressed to federal and state legislators, the Coastal Wetlands Conservation and Restoration Task Force, other decision makers, the scientific community and the general public. The following is a synopsis of the panel's report as published (Boesch *et al.* 1994), with some observations of the response to our recommendations for addressing wetland restoration at the ecosystem (and broader) scale.

The impetus behind this assessment was the loss of almost 4,000 km^2 of Louisiana's coastal wetlands between the 1930's and 1990, manifested primarily by inundation and erosion of coastal wetlands and increasing salinity stress of brackish and freshwater wetlands as saltwater has increasingly intruded into the deteriorating coastal zone. Concerned that scientific arguments calling for an ecosystem approach to restoring coastal wetlands were being ignored, regional scientific community and environmental groups (especially the Coalition to Restore Coastal Louisiana), argued that assumptions and approaches to addressing coastal wetland loss and restoration under the Coastal Wetlands Planning, Protection and Restoration Act of 1990 (CWPPRA) were deviating from fundamental scientific and technical evidence.

The mandate of the Panel was to: (1) examine space and time scales over which the fundamental processes of wetland loss operate and on which appropriate restoration strategies should be based; (2) identify issues upon which there was scientific consensus or controversy; (3) determine actions assuring the long-term (decades to centuries) continuance of extensive wetlands in coastal Louisiana; and (4) propose scientific and technical needs for research, modeling, and monitoring, including criteria for assessing the effectiveness of wetland restoration and creation. Our approach was to conduct an intensive literature and data review, undergo intensive exposure to the Louisiana coastal zone and issues, conduct two-day hearings with expert witnesses and hold panel discussions to develop conclusions.

The panel's approach to this charge was to evaluate the hierarchy of scales in landscape organization that influence ecosystem processes affecting wetland loss and development. We considered wetland loss and restoration at three distinct scales encompassing the immense heterogeneous landscape of coastal Louisiana: (1) geologic provinces, on the order of 10^4 km^2; (2) hydrological basins, 10^2 km^2; and (3) discrete communities of wetland vegetation, the "marsh scale," at 10 km^2. The principal factors catalyzing loss varied across these scales, respectively: geological, driven by large-scale subsidence of abandoned river deltas, and manifested as relative sea level rise; hydrological, driven by high water (tides, river floods, storm surges), wind and lightening (fires); and biological, driven by loss of vegetation due to dieback and herbivory. The overriding influence has been large-scale, as the lower Mississippi River changed course, abandoning old and developing new deltas, several times over the last 7,000 yr, and resulting in seven remnant deltas between the modern, active "birdsfoot" delta (70% of river flow) and the subsidiary (30% of flow) Atchafalaya River delta. We considered the wealth of evidence to support the conclusion that the accelerated wetland loss in Louisiana is fundamentally much more a consequence of sinking of the land, and deficiencies in the build-up of soil that could offset this sinking, than erosion of the margins of coastal wetlands, filling or draining. Thus, net loss of coastal wetlands in Louisiana would probably be occurring without human intervention because of the limited wetland-building potential of the extant delta. However, numerous human activities have caused the acceleration of wetlands loss, including: construction of canals for transportation and oil and gas development and the hydrologic modifications that result from them; impoundments and failed land reclamation; and interference with floodwater flow across the natural levees of the river. Without mitigation or restoration, the modifications resulting from these activities will continue to cause high rates of wetland loss. Furthermore, both the large-scale geologic processes and more localized anthropogenic influences pose very practical constraints and impediments to wetland restoration, which need to be considered in any comprehensive restoration strategy at the landscape scale.

Wetland management and restoration initiatives have the potential to reduce the loss of Louisiana's coastal wetlands. The panel concluded that:

- Reduction in the intensity of new human intervention over the past decade or so has contributed to a reduction in wetland loss rate, but regulatory protection alone will be insufficient to reduce wetland losses to a level that avoids drastic consequences to resources and human habitation and enterprise in coastal Louisiana.

- Large-scale and comprehensive management and restoration will be required and are technically feasible. If based on strong science and engineering and effectively implemented, CWPPRA provides an excellent mechanism and impetus for such a comprehensive effort.

- Planning activities under CWPPRA were off to a good start but will have to more effectively: (1) integrate region-wide strategies with those developed locally (within hydrologic basins); (2) moderate the self-interests of performing parties (e.g., federal and state agencies) by objective technical and policy review; (3) balance private land rights with the greater public interest in the integrity of coastal wetlands; and (4) attain financing for the large-scale reintroductions of freshwater and sediments which must be the backbone of effective restoration in the Deltaic Plain.

- Although there is broad consensus that reintroduction of water and sediments from the Mississippi and Atchafalaya rivers is essential for the long-term management and restoration of Louisiana coastal wetlands, questions still remain about how to achieve this most effectively, over what scales, whether there is adequate supply to meet region-wide needs, and how to evaluate the efficacy of alternative approaches.

- The effectiveness of water-level control ("marsh management") for wetland preservation and restoration is questionable; such localized approaches, although they arguably may be able to protect existing wetlands, are unlikely to contribute to a long-term increase in wetlands; active control utilizing natural processes to promote sedimentation should always be used with these measures.

- Creation of significant new wetlands is needed to offset inevitable losses, even if maintenance efforts are successful; this objective can be accomplished only by increasing the expansion of new wetlands at the (active) Mississippi River and Atchafalaya River deltas.

- Wetlands can be created by use of dredged material, but this practice cannot restore large areas of wetlands and may not be feasible in most areas removed from dredging sites.

- Large-scale (hydrologic basin-wide or province-wide, i.e., for the whole Mississippi Delta Plain or Chenier Plain) projects are necessary if wetland loss is to be reduced significantly. The Panel concluded that, given the widespread human-induced changes that have diminished the capacity of this system to build and maintain wetlands, such major coastal engineering approaches must be undertaken.

- Scientific research has served admirably as the basis for our understanding of the processes of coastal wetland loss in Louisiana; it should not be ignored when contemplating approaches to restoring the coastal wetlands and needs to be fully integrated into the planning, implementation, and evaluation processes.; modeling and monitoring procedures need to address more fully "adaptive management" strategies to improve future restoration efforts.

The "bottom line" of our assessment was that, more than any other wetland restoration effort with which we were familiar, the scope of the processes causing wetland loss in coastal Louisiana dictated the scope of any approach to restoration. It is enlightening and instructive, therefore, to examine the subsequent responses by the public, agency and scientific entities in Louisiana involved or concerned by these issues. These may be summarized in the following "hindsight" recommendations:

- Progress in integrating region-wide strategies with basin plans depends on the agency; a few have enveloped this "big-picture" concept, but response of other agencies varies, from recalcitrance to uncertainty; it appears that many participants think of big picture as a big project, rather than the coordination of some smaller projects into a regional approach.

- There has been some progress in moderating self-interest of participants by objective review, but there is also still a lot of lip-service to science; some agencies have taken initiative to address scientific rigor (such as use of modeling) but technical assessment criteria are still not uppermost in priority.

- There has also been some progress in balancing private land rights with public interest, driven primarily by public and agency frustration with the delay of projects. Land owners haven't exactly heeded that call to be more concerned about the public interest.

- A feasibility study is underway to attain financing for major freshwater and sediment diversions, although "at a snail's pace," by a lead federal agency, with some interagency/academic involvement through Water Resources Development Act funding.

- There is still no acceptance on a broad agency scale that marsh management and hydrologic restoration are questionable in their effectiveness.

My involvement in this assessment, as well as my on-going research on estuarine/coastal wetland restoration in the Pacific Northwest, has prompted me to view wetlands and wetland processes in a much larger spatial (landscape) and broader temporal context. In choosing indicators of wetland ecosystem function, I would pose the following maxims:

1. **Consider and incorporate the hierarchy of spatial and temporal scales** that influence the organization of key physical, geochemical and ecological processes affecting wetland loss and development; in particular, we need to appreciate the scales over which variability in ecosystem processes occurs, such as the inverse relationship between the frequency and intensity of disturbances effects (i.e., high frequency events tend to be associated with low intensity disturbances, and *vice versa*);

2. **Understand the role of landscape features** in regulating function; such features occur at both local (e.g., large woody debris) and broader scales (e.g., distributary channel geomorphology); requires that we understand the processes that account for these features, and their variability, as well as the direct relationship to habitat functions (e.g.,

reproduction, refuge from predation, and feeding for fish and wildlife); understanding the relationship between landscape structure (features) and ecosystem function is a fundamental prerequisite to developing both technical approaches to restoration as well as effectively assessing the outcome of a particular restoration design;

3. **Develop realistic expectations** of restoration patterns and rates, recognizing that restoration can inherently be a long-term process analogous to the variation in the development of natural ecosystems; to follow up on Paul Keddy's gauge analogy, it is important to remember that gauges don't usually have an immediate functional response—they don't come up to an operational level of function or within natural variability for some (unknown?) time; and,

4. **Acknowledge and anticipate persistent constraints**, where potential function may differ significantly from realized function because of other contingencies that operate at broader scales.

Our ultimate challenge is to select indicators that: (a) reliably predict rates and patterns of development toward desired levels of function; (b) provide sensitive tests of the trend ("trajectory") toward the desired function and simultaneously provide an indication of (contingency) modifications that might be required to right any significant deviations from desirable trends; and; (c) allow us some flexibility and adaptiveness in our restoration strategies, technical approaches and, ultimately, our expectations. At this stage of restoration science, it would behoove us to adopt a certain element of humility in understanding how we can use our meager but increasing understanding of ecosystem- and landscape-scale processes to accelerate restoration but simultaneously understand the limitations and potential counterproductive consequences of any "ecofixes" we might adopt.

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APPENDIX A-1: BACKGROUND PAPER PREPARED FOR OCTOBER WORKSHOP

ENVIRONMENTAL DEFENSE FUND

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Designing Restoration of the San Francisco Bay Delta-River Ecosystem-- A Framework for Developing Ecological Indicators and Thresholds

Discussion Paper for the Workshop "Restoration of the San Francisco Bay-Delta-River Ecosystem: Choosing Indicators of Ecological Integrity"

19 October 1995

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A new model for defining the desired state of ecosystems impacted by human activities is emerging in response to some widely-acknowledged limitations of current ecosystem protection tools. In aquatic ecosystems, for example, the normal suite of water quality standards may not protect whole natural communities, in part because standards do not exist for some processes (such as primary productivity, competition, and nutrient transformation) that are critical to ecological services (such as harvestable fish production). Some elements of ecosystem structure, such as species richness, are also not accounted for in conventional standards. Others occur at larger spatial and temporal scales than are routinely monitored. These shortcomings are particularly problematic in ecosystems such as the San Francisco Bay-Delta-River ecosystem (comprised of the watersheds of the Sacramento and San Joaquin Rivers, their delta, and the San Francisco Bay) that are highly disturbed and intensively managed. Moreover, the fact that this ecosystem is composed of many interacting systems that occur over a large geographic scale further exacerbates the problem. As a result, new, more direct measures of the most important and desirable structural and functional attributes of the ecosystem may be necessary to ensure that these attributes are protected while human use of natural resources continues.

In this paper, we briefly review concepts for defining the desired state of ecosystems and for developing indicators of desired state in order to create a common vocabulary for the workshops jointly sponsored by the Environmental Protection Agency, UC Berkeley, The Bay Institute, and the Environmental Defense Fund. We then go on to propose a strawman: an organizing framework that can be used to define the elusive concept of ecological integrity and to develop ecological indicators and target levels defining desired state for the Bay-Delta-River ecosystem. The proposed framework is based on a four-step process suggested by Keddy et al. (1993). This framework incorporates a holistic approach to restoration, encompassing both structural and functional components of an ecosystem as well as various hierarchical levels of organization. The development of a clearly defined framework has several benefits: it provides a rational basis for developing a comprehensive suite of indicators; it reduces the likelihood of failing to consider important ecosystem attributes and indicators; it enhances the ability to set priorities among indicators, if necessary; and it helps to explain the importance and function of each indicator to the scientific community and policymakers. A coherent conceptual framework also will aid in the maintenance of the restoration program and of associated long-term monitoring programs.

ECOSYSTEM HEALTH

Practitioners in the new fields of *ecosystem medicine*, *stress ecology*, and *clinical ecology* are developing and attempting to use concepts such as *ecosystem health*, *ecological integrity* and *biological integrity*. *Ecosystem health* has been defined in a variety of ways (see Table 1 for examples). Karr (1993) defines ecosystem health as the condition in which a system realizes its inherent potential, maintains a stable condition, preserves its capacity for self-repair when perturbed, and needs minimal external support for management. *Biological integrity* refers to the "ability of an ecosystem to support and maintain a balanced, integrated, adaptive biological community having a species composition, diversity, and functional organization comparable to that of natural habitat in the region" (Karr and Dudley 1981). It is important to note that *biological integrity* distinguishes between human and naturally-caused changes whereas *ecosystem health* does not (Miller 1995). New institutions have formed to advance these concepts, such as the International Society for Ecosystem Health and the Society for Ecological Restoration.

The concept of ecosystem health has most often been defined, however, by what it is *not*. David Rapport and colleagues (e.g. 1989; Rapport, Regier and Hutchinson 1985; 1984; Rapport, Regier and Thorpe 1981; Rapport, Thorpe and Regier 1979) developed the concept of an *ecosystem distress syndrome*, marked by reductions in the stability and diversity of aquatic ecosystems, elimination of the longer-lived, larger species, and a tendency to favor short-lived opportunistic species (Rapport, Regier & Hutchinson 1985). In the Great Lakes, some of the more heavily used, degraded subsystems exhibit the general distress syndrome. In case studies of these systems, likely ecological responses from each type of stress were inferred from impact assessments. A fairly comprehensive and detailed interdisciplinary set of conceptual frameworks was developed from this information, which can be used as a basis for rehabilitation of the Great Lakes ecosystem (Rapport, Regier, and Hutchinson 1985).

Additionally, Rapport et al. (1981) compare the stress response of an ecosystem (considered as an organism) to that of a mammalian system. The first response to stress is generally an alarm reaction (a characteristic change at the first exposure to stress), followed by resistance (when continued exposure leads to an adaptation), and, finally, exhaustion (irreversible damage following prolonged exposure). The five main groups of ecosystem stresses identified include: (1) harvesting of renewable resources; (2) pollutant discharges; (3) physical restructuring (including hydrologic modifications); (4) introduction of exotics; and (5) extreme natural events (Rapport, Regier & Hutchinson 1985).

ECOLOGICAL INDICATORS

Although ecological health and integrity have been defined conceptually in the literature, providing an *operational* definition-- with quantifiable measures --for the health or integrity of a particular ecosystem can prove difficult. One approach is the use of *ecological indicators* (alternatively known as metrics or state variables). Ecological indicators are components of a system whose characteristics (presence or absence, quantity, distribution) are used to represent those ecosystem attributes that are too difficult, inconvenient or expensive to measure (Landres et al. 1988). Indicators are intended to provide an assay to describe the health of an entire ecosystem, essentially 'taking nature's pulse'.

Keddy et al. (1993) suggest a four-step process for describing and predicting the states of ecosystems, using ecological indicators: (1) define health or integrity in an operational way; (2) select indicators of integrity; (3) identify target levels of the indicators that define desired states; and (4) develop a monitoring system to provide feedback that can be used to modify the indicators and their target levels as appropriate. In the following discussion, we propose a strawman framework for using these steps to develop ecological indicators for the San Francisco Bay-Delta-River ecosystem.

<u>Step 1</u>: Define health or integrity in an operational way

Step one constitutes the broad overview of an ecosystem management or restoration program, where the objectives for the program are set. Researchers ask: Are there intrinsic attributes that define health? If not, is there another way to describe a healthy ecosystem? In order to translate ecosystem health into goals for restoration, it is helpful to identify the most important elements of ecosystem structure and function necessary to support the desired state. Several policy-related and scientific groups have invested considerable time and energy into identifying a suite of goals that might be used as surrogates for ecosystem health descriptors for the Bay-Delta-River ecosystem. For example, both CALFED and the San Francisco

Estuary Project Comprehensive Conservation and Management Plan (CCMP) have produced lists of ecosystem quality objectives that may also be used for this purpose. In addition, participants in a recent workshop, entitled "Goals for Restoring a Health Estuary", sponsored by the National Heritage Institute (NHI) and others, identified some key ecosystem service goals to use in an operational definition of ecosystem integrity. Many of the goals (or ecosystem functions and services) identified by these groups are comparable to one another; others appear to be more appropriate as indicators (step two) rather than definitions of the desired state of the ecosystem (step one). In Table 2 we have assembled a preliminary, consolidated list of the goals that have been suggested by these various groups as operational definitions of ecosystem integrity. The original documents are reprinted in Appendix I. **One of the objectives for this workshop is to determine whether the list in Table 2 is both appropriate and comprehensive.** It is particularly important to consider whether ecosystem "integrity" or "health" is captured by the suite of goals presented in the table.

In the longer term, insight into the adequacy of this suite of goals can be gained by analyzing a reference system, whose attributes can be used to infer how a system with integrity might look and/or function. One technique to establish reference conditions is to reconstruct how the system looked and functioned in the past, and compare it with how it functions now. This is similar to the approach used in the Florida Everglades, where a natural system model is being designed to serve as the template for restoration. Another method is to characterize comparable ecosystems in more pristine conditions, if they exist. Both types of reference systems can provide insight into developing and refining the objectives of the program.

Once refined, the list of program goals can provide a basis for choosing ecological indicators, using a methodology described below.

<u>Step 2</u>: Select indicators of health or integrity

Many factors (scientific, economic, and sociopolitical) come into play in choosing indicators for a particular ecosystem or program. The fundamental requirement, however, is that all of the important attributes of the system be represented. The National Research Council (1992) stresses that restoration of an aquatic ecosystem requires coordinated, comprehensive management of all significant ecological elements, often on a watershed or other landscape scale.[1]

To cover all aspects of the system, many authors (e.g. National Research Council 1992; Noss 1990) suggest that a suite of indicators should include both *structural* and *functional* attributes of an ecosystem. Topography and nutrient cycling are examples of structural and functional attributes,

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[1] This kind of ecosystem-level management has gained popularity lately, and has been adopted by the National Park and US Forest Service.

respectively. (See Table 3 for additional examples.) Additionally, Noss (1990) suggests that indicators for monitoring should include several hierarchical levels of ecological organization, at multiple spatial and temporal scales. He states that "no single level of organization (e.g., gene, population, community) is fundamental, and different levels of resolution are appropriate for monitoring and protecting biodiversity." Noss also maintains that "'Big picture' research on global phenomena is complemented by intensive studies of the life histories of organisms in local environments."

Focusing exclusively on indicators of one hierarchical level has several disadvantages. For example, it has been suggested that the success of species at top trophic levels indicates the health of lower trophic levels. Organisms at top trophic levels, usually vertebrates, have often been used as indicators. Indicators of the status of "charismatic megafauna" also serve other functions, such as helping to maintain political will for restoration. However, because of their relative longevity, the actual causes of perceived declines, once detected, are often difficult to unravel (Laudenslayer 1991). For this reason, Landres et al. (1988) conclude that using vertebrates alone to indicate habitat quality for other species is not a sound method, and recommend the use of other indicators as part of a comprehensive monitoring strategy.

Monitoring at lower levels of organization within the ecosystem provides clues to the processes affecting the behavior of the whole (Rapport 1984) and may provide an early warning of ecological stress, because with this approach the ecological preconditions for a healthy ecosystem, such as primary productivity, are being monitored. Indicators of early steps in the process leading to stress may be more useful than an indicator which informs that the system is already ailing. For example, using indicator species associated with soil productivity (e.g. mycorrhizal fungi) quickly detects those effects that may be fundamental to the functioning of the system. Mycorrhizal fungi are important components in the diets of small mammals, which in turn are important diet components of carnivorous species (Laudenslayer 1991). In the case of eutrophication, monitoring nutrient flux may allow for early detection of an imminent problem, whereas monitoring of dissolved oxygen may signal changes only after it is too late for preventative measures. Additionally, when employing biota as indicators, a suite of indicators including multiple species and assemblages is more likely to provide improved detection capability over a broader range as well as protection to a larger segment of the ecosystem than single indicators(Kremen 1992; Karr 1993). One example of an indicator suite is Karr's Index of Biotic Integrity (IBI), which provides a quantifiable index of a number of ecological indicators for the assessment of the quality of water resources (Karr 1992). The IBI adopts the hierarchical approach discussed above, integrating 12 ecological characteristics, or metrics, of stream fish assemblages, classified into three major groups: species richness and composition, trophic composition, and fish abundance and condition (Karr 1987). Index scores range from 1-5, depending on how observed site conditions compare to those for a pristine reference site. Karr initially developed the IBI for use with fish communities, but the ecological foundation can be used to develop analogous indexes that apply to other taxa (Karr 1991). Miller et al. (1988) review the application of the IBI to various locations in the United States and conclude that the IBI holds promise for direct biological monitoring because of its strong ecological foundation and flexibility.

A second objective for this workshop is to provide the foundation for developing ecological indicators for the Bay-Delta-River ecosystem in a pragmatic, methodical way. These ecological indicators should assess the attainment of the goals identified in step one. In order to provide a framework that clearly outlines the logic behind the selection of specific indicators, and to ensure that the indicator suite adequately covers structural and functional ecosystem attributes as well as various hierarchical levels of organization, we suggest using Noss' (1990) conceptual model of biodiversity at multiple levels of organization (Figure 1). Figure 2 adapts Noss' figure into a proposed matrix for identifying ecological indicators at each level of organization for a particular operational definition of ecosystem integrity. A matrix would eventually be filled out for each operational attribute or goal, based on those listed in Table 2 or any others workshop participants may propose. We have attempted to fill in a matrix for the goal of "Increasing and Improving Aquatic Habitats" (Figure 3) for the purpose of illustrating what is meant by the three categories and four scale levels in the matrix; no attempt was made to ensure that the sample indicators were the most appropriate or scientifically defensible indicators possible. The utility of the proposed framework is primarily to ensure that the suite of ecological indicators adequately addresses the range of ecosystem structure and function at a variety of hierarchical levels.[2]

In filling out these matrices, some considerations about indicators must be kept in mind. Ideally, indicators should be (1) sufficiently sensitive to provide an early warning of change; (2) distributed over a broad geographical area, or otherwise widely applicable; (3) capable of providing a continuous assessment over a wide range of stress; (4) relatively independent of sample size; (5) easy and cost-effective to measure, collect, assay, and/or calculate; (6) able to differentiate between natural cycles or trends and those induced by anthropogenic stress (Noss 1990); (7) ecologically meaningful (closely related to maintenance of essential processes and functions) (Keddy et al. 1993); (8) relevant to societal concerns (Angermeier and Karr 1994); and (9) environmentally benign to measure (Barbour, Stribling & Karr 1995). Kimmerer (1995)

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[2] Missing from the strawman framework as outlined so far is an explicit treatment of specific stressors. In order to assure that the suite of ecological indicators is sensitive to and provides early warning of disruption due to stressors, we suggest that the following "check" be undertaken as part of step 2. First, a list of likely stressors for the Bay-Delta-River ecosystem should be developed. The list would probably encompass the five general stressor categories identified by Rapport, Regier and Hutchinson (1985), listed above. Second, the likely responses from each category of stressor could be explored, considering both the ecosystem attributes defined in step one and the matrices already developed in step two. Finally, the likely responses could be compared to the existing list of ecological indicators, to determine whether the indicators, combined with the routine monitoring programs already underway, will provide adequate early warning of a significant stress response.

also suggests some key features to ensure the scientific defensibility of an ecosystem health indicator: (1) Primary indicators (those monotonically related to an ecosystem property) are preferred over derived ones (those assumed to be related to some primary indicator that itself may not be measurable or interpretable); (2) easily interpretable indicators take precedent over those which require value judgments; (3) measurable indicators are preferred to conceptual ones; (4) quantitative indicators are preferred to qualitative ones; and (5) existence of a long historical data record is desirable. Many indicators have been suggested in a variety of forums (see, for example, Appendices II & III).

Step 3: Identify target levels of indicators that define integrity or lack thereof

Once indicators are selected, a range of target values, from tolerable to desirable levels, should be developed for each. Because determining the target range of indicator values from first principles is difficult, comparisons with reference systems are often used. As discussed above, the reference system can be either a similar, but more "pristine" system or a historical reconstruction of the system when it was in the desired state. In disturbed ecosystems such as the Bay-Delta-River system, it is clearly unreasonable to strive for the restoration of pristine conditions. However, an historical reconstruction can provide insights into what target levels could be, through a comparison of increasingly less disturbed states. In addition, such an approach has the advantage of being holistic. A consideration only of present-day structure and function may result in a limited and fragmentary vision and strategy for restoration. An extended discussion of methodologies for defining target levels is planned for a future workshop. In general, pilot studies also are recommended, in order to define, evaluate, and calibrate the metrics prior to full-scale implementation of the program (Kremen 1992).

Step 4: Develop a monitoring system to provide feedback

A monitoring system is crucial to the successful use of ecological indicators as a management tool. Monitoring provides a way to assess the utility of indicators and their target levels, developed in steps two and three, and then modify them if necessary. Similarly, the monitoring and assessment program allows for *adaptive management*: changes in the ecological indicators allow decision makers to determine whether the management and/or restoration program is having its intended effect. Additionally, monitoring results can be utilized as a tool for public outreach, using appropriate indicators for different audiences. For example, simplistic indicators of ecosystem health, such as the Chesapeake Bay white sneaker visibility test (a proxy for water clarity) may not be scientifically defensible, but can help inform the public and educate them about restoration efforts in their region. Post-management uses of ecological indicators include short-term evaluation of success of a project and long-term monitoring.

INSIGHTS FROM OTHER PROGRAMS

Indicators have long been employed by environmental toxicologists. However, only recently has the concept of ecological indicators been suggested for assessing the overall health of ecosystems, when contaminants are not the sole issue. Past attempts to employ ecological indicators and ecosystem-level management provide valuable lessons for applying the general approach outlined above to the Bay-Delta-River ecosystem. We describe a few examples to illustrate some lessons for the successful application of ecological indicators. One characteristic shared by all of them is an effective monitoring program.

"Soft engineering" techniques were used to restore the Blanco River in southwestern Colorado, channelized by the U.S. Army Corps of Engineers (COE) in the 1970's in a flood-control effort. Results of the channelization included channel instability, stream-bank failure, and erosion, among other problems. A landowner initiated the restoration project with the goal of "stabilizing the river in a well-carved but natural-looking permanent channel that would enable it to handle floods" (step 1 of the methodology proposed in this paper). Hydrologist D.L. Rosgen used as his reference site a similar, stable section of the river about a mile downstream from the project site. Project indicators[3] were measured at the project site and on a similar area to verify that the reconstructed reach would be able to accommodate the demands placed on it (steps 2 & 3). In the course of three years, the river's width when full was reduced from a 400-ft-wide braided channel to a single 65-ft channel with the desired characteristics: stable, deep, and slow-moving (high pool-to-riffle ratio) (Berger 1992a).

The demonstration restoration project for the Kissimmee Riverine-Floodplain System provides an example of the utility of testing a restoration plan in a small area before applying it to the larger system. The goal of the demonstration project was to show that wetland vegetation and other wildlife would readily recolonize the reflooded areas, and riverine ecosystems would respond favorably to resumption of natural flow regimes (step 1). The project successfully demonstrated that restoration of riverine-floodplain values and functions is possible, and this success has garnered much-needed support for the restoration of the larger Kissimmee system. An inter-agency monitoring program played a crucial role in demonstrating this success (step 4).[4]

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[3] Indicators used include river width, depth, velocity, discharge, slope, energy slope, roughness, sediment load, sediment size, sinuosity, width-to-depth ratio, dominant particle size of bed and bank materials, entrenchment of channel, confinement of channel, landform confinement of channel, landform features, soil erodibility, and stability.

[4] The South Florida Water Management District (SFWMD) monitored the effect of hydrologic changes on floodplain vegetation, floodplain fish, secondary productivity, benthic invertebrates, and river channel habitat characteristics. Other agencies, including the Florida Game and Fresh Water Fish Commission and the Florida Department of Environmental Regulation, conducted alligator counts, bird surveys, fish population samples, water quality monitoring, and measurements of aquatic macroinvertebrate and periphyton responses.

Some particularly successful components of the Kissimmee project include: (1) setting explicit goals (i.e. restoration of ecological integrity) in advance; (2) not establishing criteria in terms of numbers of fish or waterfowl to be restored, which avoided battles among different user groups; (3) a more extensive scientific peer-review process than most restoration projects have; (4) use of hydrologic models to establish probable outcomes for some of the nonbiological aspects of alternative restoration plans, which reduced uncertainty about these outcomes; (5) monitoring designed from an ecosystem perspective; and (6) a major public education effort on the part of scientists and engineers to acquaint people with the complexities of ecological restoration (Berger 1992b).

The goal in the creation of Sweetwater Marsh National Wildlife Refuge was to create nesting habitat for the light-footed clapper rail (*Rallus longirostris levipes*), and foraging habitat for the California least tern (*Sterna antillarum browni*) (step 1). Restoration of some 128 ha of wetlands and some uplands along the east side of San Diego Bay began in 1984 with the excavation of approximately 4.9 ha of disturbed upper intertidal marsh, including areas previously used as an urban dump. The managers used soil nitrogen concentrations as well as a "functional equivalency index" to compare constructed and natural wetland functioning (step 2). For each of 11 marsh attributes,[5] mean values for the constructed marsh were expressed as percentages of the mean value for a reference wetland (step 3). A monitoring program to assess plant cover and faunal use was implemented from the outset of the project. The results indicated less than 60% equivalency when the marsh was 4-5 years of age (step 4). The project's exceptionally high criteria for judging success serves as a model for future restoration efforts (National Research Council 1992). Whether or not this restoration project was a success in terms of created habitat for birds, the use of a reference condition by which to evaluate the project can be considered successful.

Ecological indicators can also be used to provide insight into the state of non-managed systems. For example, the United States Environmental Protection Agency (USEPA) initiated a nationwide environmental monitoring and assessment program (EMAP), with the goal of "establishing baseline conditions against which future changes can be documented with confidence" (Breckenridge et al. 1995). In the context of this project, the operational definition of ecological integrity is based upon societal values (step 1). The program classifies its indicators into four types (response, exposure, habitat, and stressor) to evaluate habitat productivity, biological integrity, and aesthetics: the focal points of the program (Hunsaker, Carpenter and Messer 1990). *Response indicators* quantify the overall biological conditions of ecosystems

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[5] Attributes include organic matter content, sediment inorganic nitrogen, sediment nitrogen total Kjeldahl nitrogen (TKN), pore-water inorganic nitrogen, nitrogen fixation (surface cm.), nitrogen fixation (rhizosphere), biomass of vascular plants, foliar nitrogen concentration, height of vascular plants, epibenthic invertebrate numbers, and epibenthic invertebrate species lists.

by measuring either organisms, populations, communities, or ecosystem processes. *Exposure indicators* measure ecosystem exposure to toxics, nutrients, heat, acidity, and ionizing or electromagnetic radiation. *Habitat indicators* represent conditions on a local or landscape scale that are necessary to support a population or community (e.g. availability of snags, vegetation cover, vertical layers of vegetation). *Stressor indicators* reflect activities or occurrences that cause changes in exposure or habitat conditions and include pollutant, management, and natural process indicators (e.g. number of wastewater discharges, proximity to urban areas, and introduction of exotic species) (Hunsaker, Carpenter and Messer 1990) (step 2).

Another important element of successful restoration projects has been careful scientific and political consensus-building, such as the process employed for deciding upon the X_2 salinity standard for the Bay-Delta-River ecosystem. Participants in a series of workshops sponsored by the San Francisco Estuary Project agreed upon a scalar index consisting of the position of a particular near-bottom isohaline as a "policy" variable that could be used to set standards for managing freshwater inflow (step 1 & 2). Participants then agreed upon the 2% near-bottom isohaline (denoted as X_2) in particular for further exploration (Jassby et al. 1995) (step 3). Some of the workshop participants later tested the choice of X_2 and found that it has a clear and pervasive relationship with estuarine biological properties, demonstrates integration of effects over space and time, has unambiguous relationships with many habitat variables (including salinity distribution and net outflow from the Delta), is quantifiable by automated or synoptic monitoring, is important to ecological structure and function, responds to stressors and management strategies, can be measured by a standard method, has low measurement error, has a historical data base, and can be considered cost-effective (Jassby et al. 1995) (step 4). These are all attributes considered critical or desirable for habitat indicators by the USEPA's EMAP program (Messer 1990). They also meet many of the criteria described in the section on step two of this paper.

CURRENT OPPORTUNITIES

Provisions of the Bay-Delta Accord and the Central Valley Project Improvement Act (CVPIA), combined with requirements of the Endangered Species Act (ESA) and the Clean Water Act (CWA), provide an unprecedented opportunity to carry out protection and restoration measures for the Bay-Delta-River ecosystem. CALFED, a state-federal program launched in the wake of the Bay-Delta water accord of last December, is currently in the process of exploring restoration plans for the Bay-Delta-River ecosystem, with the target of formulating preliminary alternative packages by early next year. Additionally, a variety of private sector interests are attempting to achieve consensus on key issues related to California's water resources. The variety of ecosystem types involved and the complexity of the issues will prove challenging obstacles to restoration. If a holistic ecosystem approach to the Bay-Delta-River restoration program is to be embraced, now is the time to advance it and build consensus for it. Ecological indicators and targets may prove to be useful tools to facilitate ecological restoration and continued human use.

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Table 1: Some proposed descriptors of ecosystem health.

Ecosystem health descriptor	**Definition**
Costanza (1992):	
• Homeostasis	Maintenance of a steady state in living organisms by the use of feedback control processes
• Absence of disease	Lack of stress, or perturbation with particular negative effects on the system
• Diversity/Complexity	Evenness and richness of species.
• Stability/resilience	How fast the variables return towards their equilibrium following a perturbation. Not defined for unstable systems
• Vigor/scope for growth	Overall metabolism or energy flow
• Balance	Proper balance exists between system components
Westman (1978):	
• Resilience	Degree, manner, and pace of restoration of initial structure and function in an ecosystem after disturbance
• Inertia	Ability of a system to resist displacement in structure or function when subjected to a disturbing force
• Elasticity	Time involved in restoration
• Amplitude	Degree of brittleness of the system; threshold beyond which ecosystem repair to the initial state no longer occurs
• Hysteresis	Degree to which the pattern of recovery is not simply a reversal of the pattern of initial alteration
• Malleability	The ease with which the system can become permanently altered; compare the new stable state to the former one
National Research Council (1992):	
• Persistence	The ability of the ecosystem to undergo natural successional processes or persist in a climax sere, all without active human management
• Verisimilitude	A broad, summative, characteristic of the restored ecosystem reflecting the overall similarity of the restored ecosystem to the standard of comparison, be it prior conditions of the ecosystem or of a reference system

Table 2: Some proposed operational definitions of ecosystem integrity and sources from which they were derived.* The operational definitions of ecosystem integrity in the first column can be used to fill in the blank at the top of the matrix in Figure 2.

OVERALL GOAL:	**Source:**
• **Improve, increase, restore and protect aquatic and terrestrial habitats and improve ecological functions in the Bay-Delta-River ecosystem to support sustainable, diverse, balanced and healthy populations of plant and animal species, focusing on indigenous species**	-Improve and increase aquatic and terrestrial habitats and improve ecological functions in the Bay/Delta to support sustainable populations of diverse and valuable plants and animal species (CALFED) - Restore and protect a diverse, balanced and healthy population of fish, invertebrates, wildlife, plants and their habitats, focusing on indigenous species (CCMP)
OPERATIONAL DEFINITION OF ECOSYSTEM INTEGRITY:	**Source:**
Habitat	
• **Improve and increase <u>aquatic</u> habitats (including riverine, delta, estuarine, and bay)**	- Improve and increase aquatic habitats so that they can support the sustainable production and survival of native and other desirable estuarine and anadromous fish in the estuary (CALFED)
• **Improve and increase <u>terrestrial</u> habitats (including wetland, riparian, upland and ???)**	- Improve and increase important wetland habitats so that they can support the sustainable production and survival of wildlife species (CALFED)
Biota	
• **Stem and reverse the decline in the health, abundance, and species richness of <u>aquatic</u> biota (native and desirable non-indigenous) with an emphasis on natural production (for riverine, delta, estuarine, and bay systems)**	- Stem & reverse the decline in the health and abundance of estuarine biota (native and desirable non-indigenous) with an emphasis on natural production (CCMP) - Stem & reverse the decline of estuarine plants and animals and the habitats on which they depend (CCMP) - Increase population health and population size of Delta species to levels that assure sustained survival (CALFED) - Restoration goals for anadromous fish are equal to, or at least twice the mean estimated natural production for the baseline period of 1967-1991 (DPlan)
• **Stem and reverse the decline in the health, abundance, and species richness of <u>terrestrial</u> biota (native and desirable non-indigenous) with an emphasis on natural production (for wetland, riparian, upland, and ??? systems)**	- Restore populations of indigenous species to levels not likely to result in extinction (NHI-WS)

Table 2 (continued)

• Ensure the survival and recovery of listed and candidate <u>aquatic</u> endangered and threatened species, as well as other species in decline	- Ensure the survival & recovery of listed and candidate (aquatic) species, as well as other species in decline (CCMP) - Establish self-sustaining populations of the species of concern that will persist indefinitely (NF)
• Ensure the survival and recovery of listed and candidate <u>terrestrial</u> endangered and threatened species, as well as other species in decline	- Ensure the survival & recovery of listed and candidate (terrestrial) endangered and threatened species, as well as special status species (CCMP)
Ecosystem Services & Functions	
• Provide commercial and sport-fishing opportunities	- Provide anglers with a reasonable chance of catching sport fish (NHI-WS) - Increase naturally-produced populations of anadromous fish (NHI-WS) - Chinook salmon, green sturgeon and splittail - recovery goals include having large enough populations so that a limited harvest can once again be sustained (NF)
• Preserve and restore the capacity of the system to provide essential ecosystem services, including (1) flood control, (2) water quality enhancement, (3) erosion control, (4) recreation, and (5) aesthetic enjoyment	- Preserve and restore wetlands to provide habitat for wildlife, improve water quality and protect against flooding (CCMP) - Restore and enhance the ecological productivity and habitat values of wetlands (CCMP) - Enhance aesthetic values (NHI-WS)

* Sources are cited as follows: "San Francisco Estuary Project Comprehensive Conservation and Management Plan", 1992 (CCMP); "Draft: CALFED Bay/Delta Program- Ecoystem Quality Objectives Statements" (CALFED); "Recovery Plan for the Sacramento-San Joaquin Delta Native Fishes: Technical/Agency Draft", 12/94 (NF); "Working Paper on Restoration Needs: Habitat Restoration Actions to Double Natural Production of Anadromous Fish in the Central Valley of California" (DPlan); Draft Report on the National Heritage Institute Definitional Workshop, "Goals for Restoring a Healthy Estuary" (NHI-WS).

Table 3: Possible structural and functional ecological assessment criteria, over a range of ecological levels of organization. Taken from *National Research Council (1992)* unless otherwise noted.

STRUCTURE	FUNCTION
Water quality (dissolved O_2, dissolved salts, dissolved toxics and other contaminants, floating or suspended matter, pH, odor, opacity, temperature profiles)	**Decomposition rate** (Landres 1992)
Soil condition (soil chemistry; erodibility; permeability; organic content; soil stability; physical composition, including particle sizes and microfauna)	**Surface and ground water storage, recharge, and supply**
Geological condition (surface and subsurface rock and other strata, including aquifers)	**Floodwater and sediment retention**
Hydrology (quantity of discharge on annual, seasonal, and episodic basis; timing of discharge; surface flow processes, including velocities, turbulence, shear stress, bank/stream storage, and exchange processes; ground water flow and exchange processes; retention times; particle size distribution and quantities of bed load and suspended sediment; and sediment flux (aggradational or degradational tendencies) (Rosgen 1988))	**Transport of organisms, nutrients, and sediments**
Topography (surface contours; the relief (elevations and gradients) and configuration of site surface features; and project size and location in the watershed, including position relative to similar or interdependent ecosystems)	**Humidification of atmosphere** (by transpiration and evaporation)
Morphology (shape and form of the ecosystem, including subsurface features)	**Oxygen production**
Flora and fauna (species richness, guild structure, functional dominance (Landres 1992), density, diversity, growth rates, longevity, species integrity (presence of full complement of indigenous species found on the site prior to disturbance), productivity, stability, reproductive vigor, size- and age-class distribution, impacts on endangered species, incidence of disease, genetic defects, genetic dilution (by nonnative germ plasm), elevated body burdens of toxic substances, and evidence of biotic stress)	**Nutrient cycling** (loss of, turnover, horizontal transport, vertical cycling (Landres 1992))
Carrying capacity, food web support, and nutrient availability as determined for specific indicator species	**Biomass production, food web support, and species maintenance** (primary productivity, production : respiration and production : biomass ratios (Landres 1992))
	Provision of shelter for ecosystem users (e.g. from sun, wind, rain, or noise)
	Detoxification of waste and purification of water
	Reduction of erosion and mass wastage
	Energy flow

Figure 1: Compositional, structural, and functional biodiversity, shown as interconnected spheres, each encompassing multiple levels of organization. This conceptual framework may facilitate selection of indicators that represent the many aspects of biodiversity that warrant attention in environmental monitoring and assessment programs (Taken from Noss 1990).

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Figure 2: Proposed matrix for identifying ecological indicators at each level of organization for a particular operational definition of ecosystem integrity.

OPERATIONAL DEFINITION OF ECOSYSTEM INTEGRITY: ____________________

STRUCTURAL ELEMENTS	STRUCTURAL PATTERNS	FUNCTIONAL ATTRIBUTES
Landscape types	Landscape patterns	Landscape processes and disturbances, land-use trends
Communities, ecosystems	Habitat Patterns	Interspecific interactions, ecosystem processes
Species, populations	Population structure	Demographic processes, life histories
Genetic, Biochemical, Physiological Elements	Genetic structure	Genetic processes

Adapted from Noss (1990)

Figure 3. Strawman matrix with examples of possible indicators

OPERATIONAL DEFINITION OF ECOSYSTEM INTEGRITY: Improve and Increase Aquatic Habitats

STRUCTURAL ELEMENTS	STRUCTURAL PATTERNS	FUNCTIONAL ATTRIBUTES
Landscape types	**Landscape patterns**	**Landscape processes and disturbances, land-use trends**
Rivers (various order streams, floodplains) Delta (including sloughs) Estuary (including X-2) Bay (including Suisun, San Pablo, Central, South)	Connectivity between protected and restored habitats The right habitats in the right places Degree of stream sinuosity	Survival rates of all life cycle phases of desired species Degree of resemblance between actual hydrograph and natural hydrograph
***Communities, ecosystems**	***Habitat patterns**	***Interspecific interactions, ecosystem processes**
Extent of shaded riparian zones Extent of shallow riverine habitat Extent of river edge habitat Type and amount of large woody debris	Pool-to-riffle ratio Relative amounts of habitat types Minimum habitat size	Bank stability, nutrient and sediment retention Nutrient loading, transformation Production of forage for desired species Primary productivity by desired species Toxic compound concentrations
***Species, populations**	***Population structure**	***Demographic processes, life histories**
Appropriate spawning sites Appropriate water quality conditions Desirable forage for target organisms Indicator species (e.g., benthic invertebrates, water hyacinth, native fish species, salmon) Fish condition	Age structure Spawning sites located where water is clear, cold, and flowing at appropriate speed	Competition Population resilience Spawner-to-recruit ratio Water quality parameters (e.g., temperature, dissolved oxygen, toxic compounds)
***Genetic, Biochemical, Physiological Elements**	***Genetic structure**	***Genetic processes**
Mixed-function oxidase activity	Pattern of gene distribution within and among populations	Water quality parameters (e.g., temperature, dissolved oxygen, toxic compounds)

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APPENDIX A-2: ANNOTATED BIBLIOGRAPHY OF REFERENCE SOURCES ON THE SUBJECTS OF ECOLOGICAL INTEGRITY AND ECOLOGICAL INDICATORS

ANNOTATED BIBLIOGRAPHY

Assembled by the Environmental Defense Fund for the Workshop "Restoration of the San Francisco Bay-Delta-River Ecosystem: Choosing Indicators of Ecological Integrity"

ECOSYSTEM HEALTH / ECOLOGICAL INTEGRITY:

• **Angermeier, P. L. and J. R. Karr. 1994. Biological Integrity versus Biological Diversity as Policy Directives. BioScience 44(10): 690-697.**
This paper examines the distinction between biological *integrity* and biological *diversity*, arguing that resource policy would be most effective if based on the more comprehensive goal of protecting biological integrity. The authors include some discussion of ecological indicators and ecological restoration as well.

• **Costanza, R., B. G. Norton, and B. D. Haskell, eds. 1992. Ecosystem Health: New goals for environmental management. Washington, D.C.: Island Press.**
Economists, ecologists, philosophers, public policymakers, anthropologists, sociologists, and environmental management agency personnel will find this text to be a valuable reference. It presents issues on the concept of health as it relates to ecosystems. Two sections cover topics on philosophy and ethics, and science and policy. Tables and references supplement this publication. It is based on two meetings, one held in 1990 and the other in 1991. Especially: Haskell, Norton & Costanza (Introduction: *What is Ecosystem Health and Why Should We Worry About It?*); Karr (Chapter 13: *Ecological Integrity: Protecting Earth's Life Support Systems*); Costanza (Chapter 14: *Toward an Operational Definition of Ecosystem Health*).

• **Odum, E. P. 1985. Trends expected in stressed ecosystems. BioScience 35: 419-422.**
"When ecosystems are not suffering from unusual external perturbations, we observe certain well-defined developmental trends. Since disturbance tends to arrest, or even reverse, these autogenic developments, we can anticipate some ecosystem responses to stress. Trends expected in stressed ecosystems include changes in energetics, nutrient cycling, and community structure and function." (Author's abstract).

• **Rapport, D. J. 1984. State of Ecosystem Medicine. Pages 315-324 *in* Cairns, V. W., P. V. Hodson, and J. O. Nriagu, eds. Contaminant Effects on Fisheries. John Wiley and Sons: New York.**
"Ecosystem medicine is in its infancy. While the signs and symptoms of severely disturbed environments are now reasonably well established, few indicators have been found that provide early warning and diagnostic potential. Diagnosis is further made difficult since many stresses produce the same set of symptoms, and ecosystems are often impacted upon by multiple stresses acting in complex synergistic and occasionally antagonistic modes. In the development of ecosystem practice, much can be learned from medical procedures, especially in the design of treatment protocols, and in recognition of the dangers and risks of various treatment options." (Author's summary).

• **Rapport, D. J. 1989. What Constitutes Ecosystem Health? Perspectives in Biology and Medicine 33(1): 120-132.**
"There are three approaches commonly taken to the question of the health of nature. Most attention, as in human medicine, is given to signs and symptoms of pathology. Their absence allows the presumption that the ecosystem is in a healthy condition. A second approach involves monitoring recovery times after disturbance. ... Measures of the time required for the return of 'normal' conditions provides a measure of counteractive capacity. A third approach examines health status on the basis of potential threats from exposures to known stresses. Such assessments depend on case histories of similar ecosystems exposed to the same type of stress (e.g., the effects of oil spills on coastal marine environments). To determine health status, somewhat different criteria may be applied to managed ecosystems compared to natural or 'pristine' systems. However, in both cases a primary consideration is the extent to which ecological integrity is preserved and the ecosystem is sustainable. Forming, as they do, somewhat arbitrarily conceived entities embedded in a larger three-dimensional space, ... the health of ecosystems ultimately both depends on and determines conditions in regional and global environments." (Author's summary, shortened).

• **Rapport, D. J., H. A. Regier, and T. C. Hutchinson. 1985. Ecosystem Behavior Under Stress. The American Naturalist 125(5): 617-640.**
"The behavior of ecosystems under stress can be shown to be analogous to Selye's characterization (1973, 1974) of the response of higher organisms to stress. The ecosystem-level distress syndrome is manifest through changes in nutrient cycling, productivity, the size of dominant species, species diversity, and a shift in species dominance to opportunistic shorter-lived forms. These symptoms of ecosystem dysfunction are common in both terrestrial and aquatic systems under various stress impacts including harvesting, physical restructuring, pollutant discharges, introductions of exotic species, and extreme natural events (such as disastrous storms or volcanic activity). The progression of appearance of symptoms under intensifying stress levels may be interrupted temporarily as ecosystem homeostasis and homeorhetic mechanisms intercede. Inability to cope leads to further dysfunction and, perhaps, to irreversible ecosystem breakdown." (Authors' summary).

• **Rapport, D. J., H. A. Regier, and C. Thorpe. 1981. Diagnosis, Prognosis, and Treatment of Ecosystems under Stress. Pages 269-280 *in* Barrett, G. W. and R. Rosenberg, eds. Stress Effects on Natural Ecosystems. John Wiley & Sons Ltd.: New York, NY.**
"... In this paper we explore the application of concepts and the practice of human medicine to the development of new directions in stress ecology. Our purpose is not merely heuristic. We believe that the application of the experience of medical practice to stress ecology will provide a more rigorous approach to the questions of diagnosis and treatment of degraded ecosystems and that the analogy suggests novel and worthwhile research questions that will increase our understanding of ecosystem breakdown and recovery processes." (Taken from the introduction).

• **Schaeffer, D. J., E. E. Herricks, and H. W. Kerster. 1988. Ecosystem Health: I. Measuring Ecosystem Health. Environmental Management 12(4): 445-455.**
"Ecosystem analysis has been advanced by an improved understanding of how ecosystems are structured and how they function. Ecology has advanced from an emphasis on natural history to consideration of energetics, the relationships and connections between species, hierarchies, and systems theory. Still, we consider ecosystems as entities with a distinctive character and individual characteristics. Ecosystem maintenance and preservation form the objective of impact analysis, hazard evaluation, and other management or regulation activities. In this article we explore an approach to ecosystem analysis which identifies and quantifies factors which define the condition or state of an ecosystem in terms of health criteria. We relate ecosystem health to human/nonhuman animal health and explore the difficulties of defining ecosystem health and

suggest criteria which provide a functional definition of state and condition. We suggest that, as has been found in human/nonhuman animal health studies, disease states can be recognized before disease is of clinical magnitude. Example disease states for ecosystems are functionally defined and discussed, together with test systems for their early detection." (Authors' abstract).

• Westman, W. E. 1978. Measuring the Inertia and Resilience of Ecosystems. BioScience 28(11): 705-710.
This paper discusses the concepts of resilience ("the degree, manner, and pace of restoration of initial structure and function in an ecosystem after disturbance") and inertia ("the ability of a system to resist displacement in structure or function when subjected to a disturbing force") with reference to ecosystems. A table of characteristics of resilience and examples of their application is included; they include inertia, elasticity, amplitude, hysteresis, and malleability.

• Woodley, S., J. Kay, and G. Francis, eds. 1993. Ecological integrity and the management of ecosystems. Delray Beach, FL: St. Lucie Press.
"Integrity, when applied to ecosystems, refers to an ecosystem's ability to maintain complex community structural and functional characteristics generally, but not precisely, paralleling that ecosystem's pristine state. This text presents a detailed review of ecological integrity, incorporating the critical roles of anthropogenic stresses, cultural acceptability, and active human management. Most of the examples and case studies are from Canadian ecosystems, but the principles and practices are widely applicable in all temperate systems. The text is illustrated and heavily referenced, but not indexed." (Authors' abstract). Especially: Keddy, Lee & Wisheu (*Choosing Indicators of Ecosystem Integrity: Wetlands as a Model System*); Karr (*Measuring Biological Integrity: Lessons from Streams*); Munn (*Monitoring for Ecosystem Integrity*).

EVALUATION / ASSESSMENT / MONITORING:

• Davis, W. S. and T. P. Simon, eds. 1995. Biological Assessment and Criteria: Tools for Water Resource Planning. Boca Raton, FL: Lewis Publishers.
"This book presents a state-of-the-art overview of applying biological assessments and biocriteria for water quality management in freshwaters. Case studies are presented which illustrate how different states have used bioassessment to identify and diagnose water quality problems. Examples are also provided of the use of narrative and quantitative biocriteria as regulatory tools to complement water quality criteria and standards. ... Thus the book provides useful and timely information for water quality managers." (Taken from the foreword). Especially: Hughes (Chapter 4: *Defining Acceptable Biological Status by Comparing with Reference Conditions*); Barbour, Stribling & Karr (Chapter 6: *Multimetric Approach for Establishing Biocriteria and Measuring Biological Condition*); Simon & Lyons (Chapter 16: *Application of the Index of Biotic Integrity to Evaluate Water Resource Integrity in Freshwater Ecosystems*).

• Karr, J. R. 1993. Defining and Assessing Ecological Integrity: Beyond Water Quality. Environmental Toxicology and Chemistry 12: 1521-1531.
"Emphasis in environmental protection is shifting from primary attention to human health to a more balanced consideration of human and ecological health. This shift provides opportunities and challenges to the scientific community. For example, success depends on development of operational definitions of ecological health and programs to measure that health. Ecological health is inextricably tied to concepts such as biological diversity and biological integrity. Water chemistry and toxicity testing have dominated water-quality programs for decades. Success in protecting the ecological health of water resources depends on our ability to supplement those methods with ecologically robust approaches. Existing definitions and approaches for measuring the quality of water resources provide a template to guide development of procedures to assess ecological health. Critical components of successful monitoring programs should include evaluations relative to regional expectations, use multimetric indexes that reflect the multivariate

nature of biological systems, and include index components (metrics) that evaluate conditions from individual, population, assemblage, and landscape perspectives." (Author's abstract).

• **Kondolf, G. M. 1995. Five Elements for Effective Evaluation of Stream Restoration. Restoration Ecology 3(2): 133-136.**
"River and stream restoration projects are increasingly numerous but rarely subjected to systematic post-project evaluation. The few such evaluation studies conducted have indicated a high percentage of failures. Thus, post-project evaluation (and dissemination of results) is essential if the field of river restoration is to advance. Effective evaluation of project success should include: (1) *Clear objectives*, essential to identify potential incompatibilities among project objectives and to provide a framework for design of project evaluation. (2) *Baseline data*, needed as an objective basis for evaluating change caused by the project and encompassing as long a pre-project period as possible (including a detailed historical study). (3) *Good study design*, to demonstrate the effects of restoration projects in the complex riverine environment. (4) *Commitment to the long term*, to detect effects evident only years following project completion; in general, monitoring should continue for at least a decade, with surveys conducted after each flood above a predetermined threshold. (5) *Willingness to acknowledge failures*, or rather to recognize that each restoration project constitutes an experiment, so that a failure can be just as valuable to the science as a success, provided we can learn from it (which requires objective, robust post-project evaluation)." (Author's abstract.)

• **Kondolf, G. M. and E. R. Micheli. 1995. Evaluating Stream Restoration Projects. Environmental Management 19(1): 1-15.**
"River and stream restoration projects are increasingly numerous but rarely subjected to systematic postproject evaluation. Without conducting such evaluation and widely disseminating the results, lessons will not be learned from successes and failures, and the field of river restoration cannot advance. Postproject evaluation must be incorporated into the initial design of each project, with the choice of evaluation technique based directly upon the specific project goals against which performance will be evaluated. We emphasize measurement of geomorphic characteristics, as these constitute the physical framework supporting riparian and aquatic ecosystems. Techniques for evaluating other components are briefly discussed, especially as they relate to geomorphic variables. Where possible, geomorphic, hydrologic, and ecological variables should be measured along the same transects. In general, postproject monitoring should continue for at least a decade, with surveys conducted after each flood above a predetermined threshold. Project design should be preceded by a historical study documenting former channel conditions to provide insights into the processes responsible for the present channel condition and to suggest earlier, potentially stable channel configurations as possible design models." (Authors' abstract).

• **Rapport, D. J., C. L. Gaudet, and P. Calow, eds. 1995. Evaluating and Monitoring the Health of Large-Scale Ecosystems. Berlin: Springer.**
This book emerged out of a NATO-funded workshop, which involved a series of formal presentations that provide the basis of the chapters in this volume. The chapters are arranged in five sections (*Defining Ecosystem Health; Quantitative Indices for Ecosystem Health Assessment; Diagnostic Approaches; Recovery and Rehabilitation of Large-Scale Ecosystems;* and *Methodological Issues in Design and Analysis of Ecosystem Health*) starting with definitions and measures and moving towards application and management. Major conclusions and recommendations resulting from the workshop are included in the *Workshop Summary*.

ECOLOGICAL INDICATORS:

• **Cairns, J., Jr., P. McCormick, and B. Niederlehner. 1991. A Proposed Framework for Developing Indicators of Ecosystem Health for the Great Lakes Region. Report to the International Joint Commission. Canada. July, 1991.**
• **Also published as: Cairns, J., Jr., P. McCormick, and B. Niederlehner. 1993. A Proposed Framework for Developing Indicators of Ecosystem Health. Hydrobiologia 263(1): 1-44.**
"Considerations involved in developing a suite of indicators to monitor regional environmental health, similar in conception to management use of 'leading economic indicators', are described. Linkages between human activities and well being and the state of the environment are considered essential to the evaluation of general environmental health. Biogeochemical and socioeconomic indicators are mutually affected by environmental degradation and examples of both categories of indicators are described. Desirable properties in indicators of environmental health vary with their specific management use. Different indicators are called for when collecting data to assess the adequacy of the environment, monitor trends over time, provide early warning of environmental degradation, or diagnose the cause of an existing problem. Tradeoffs between desirable characteristics, costs, and quality of information are inevitable when choosing indicators for management use. Decisions about what information to collect for which purpose can be made more rationally when available indicators are characterized and matched to management goals." (Authors' abstract).

• **Hunsaker, C. T. and D. E. Carpenter, eds. 1990. Ecological Indicators for the Environmental Monitoring and Assessment Program. EPA 600/3-90/060. United States Environmental Protection Agency, Office of Research and Development, Research Triangle Park, NC.**
A thorough description/overview of the use of ecological indicators in the EMAP program of the USEPA. "This document serves as the initial basis for the development of an indicator research plan to be implemented for the long-term monitoring in EMAP. The concepts presented here are intended to facilitate consistency among the resource groups selecting, evaluating, and developing indicators for monitoring." Fully referenced. Includes sections on EMAP indicator concepts, indicator strategies for near-coastal waters, inland surface waters, wetlands, forests, arid lands, agro-ecosystems, multiple resource categories, and atmospheric stressors plus indicator fact sheets for each of these systems.

• **Hunsaker, C. T., D. E. Carpenter, and J. Messer. 1990. Ecological Indicators for Regional Monitoring. Bulletin of the Ecological Society of America 71: 165-172.**
This paper summarizes the components of the U.S. EPA Office of Research and Development's Environmental Monitoring and Assessment Program (EMAP). The program grew out of the need to establish baseline conditions against which future changes can be documented with confidence. The paper outlines the objectives of the program and provides detailed tables and figures about the program's design, activities, and different types of indicators (response, exposure, habitat, and stressor) used.

• **Landres, P. B., J. Verner, and J. W. Thomas. 1988. Ecological Uses of Vertebrate Indicator Species: A Critique. Conservation Biology 2(4): 316-328.**
"Plant and animal species have been used for decades as indicators of air and water quality and agricultural and range conditions. Increasingly, vertebrates are used to assess population trends and habitat quality for other species. In this paper we review the conceptual bases, assumptions, and published guidelines for selection and use of vertebrates as ecological indicators. We conclude that an absence of precise definitions and procedures, confounded criteria used to select species, and discordance with ecological literature severely weaken the effectiveness and credibility of using vertebrates as ecological indicators. In many cases the use of ecological

indicator species is inappropriate, but when necessary, the following recommendations will make their use more rigorous: (1) clearly state assessment goals, (2) use indicators only when other assessment options are unavailable, (3) choose indicator species by explicitly defined criteria that are in accord with assessment goals, (4) include all species that fulfill stated selection criteria, (5) know the biology of the indicator in detail, and treat the indicator as a formal estimator in conceptual and statistical models, (6) identify and define sources of subjectivity when selecting, monitoring, and interpreting indicator species, (7) submit assessment design, methods of data collection and statistical analysis, interpretations, and recommendations to peer review, and (8) direct research at developing an overall strategy for monitoring wildlife that accounts for natural variability in population attributes and incorporates concepts from landscape ecology." (Authors' abstract).

• Laudenslayer, W. F., Jr. 1991. Environmental Variability and Indicators: A Few Observations. Proceedings of the Symposium on Biodiversity of Northwestern California, October 28-30. Santa Rosa, CA:

"The environment of the earth is exceedingly complex and variable. Indicator species are used to reduce that complexity and variability to a level that can be more easily understood. In recent years, use of indicators has increased dramatically. For the Forest Service, as an example, regulations that interpret the National Forest Management Act require the use of indicator species for monitoring the effects of management actions. Although indicators have been in use for a relatively long period of time and such use is increasing, there are a number of problems associated with the use of indicators that need to be examined. These problems include selection criteria that preclude selection of useful indicators; lack of knowledge about what environmental characteristics, if any, they indicate; and selection of single indicators to monitor complex problems. Given the problems associated with the application of the environmental indicator concept, do indicators have a role to play in the management of forests and other systems? Use of indicators can substantially reduce the complexity and costs of collecting information and monitoring. They also reduce the complexity of environmental issues to a level that can be more easily understood by resource decision-makers and the general public." (Author's abstract).

• McKenzie, D. H., D. E. Hyatt, and V. J. McDonald, eds. 1992. Ecological Indicators. London: Elsevier Applied Science.

"Recognizing the need for improved information on environmental condition, the International Symposium on Ecological Indicators was developed to explore both the enormous potential of ecological indicators and the substantial issues surrounding their development and implementation. The first objective was to present state-of-science information on the identification, application, research, and monitoring of ecological indicators. The second objective was to discuss the use and interpretation of indicator information, especially as it affects policy decisions and regulatory processes. Sections in Volume 1 (I-IX) discuss global environmental condition and the use of ecological indicators to determine status of specific resource systems. Volume 2 sections (X-XVII) identify issues in and approaches for implementing ecological indicator information. [Section I: Environmental condition; II: Determining and communicating the environmental agenda; III: Ecological indicators; IV-IX: Ecosystems monitoring (surface water, forest, near coastal, wetland, agroecosystem, and arid ecosystem monitoring). Section X-XII: Landscape, regional, and global monitoring scales; XIII-XV: Trend detection, determining the effectiveness of environmental regulations, and diagnostics and association of causes and effects; XVI: The present and future of ecological monitoring; XVII: Perspectives and priorities.] This comprehensive, 2-volume symposium proceedings thoroughly explores the development and application of ecological indicators." (Taken from the preface).

• Noss, R. F. 1990. Indicators for Monitoring Biodiversity: A Hierarchical Approach. Conservation Biology 4(4): 355-364.

"Biodiversity is presently a minor consideration in environmental policy. It has been regarded as too broad and vague a concept to be applied to real-world regulatory and management problems.

This problem can be corrected if biodiversity is recognized as an end in itself, and if measurable indicators can be selected to assess the status of biodiversity over time. Biodiversity, as presently understood, encompasses multiple levels of biological organization. In this paper, I expand the three primary attributes of biodiversity recognized by Jerry Franklin- composition, structure, and function- into a nested hierarchy that incorporates elements of each attribute at four levels of organization: regional landscape, community-ecosystem, population-species, and genetic. Indicators of each attribute in terrestrial ecosystems, at the four levels of organization, are identified for environmental monitoring purposes. Projects to monitor biodiversity will benefit from a direct linkage to long-term ecological research and a commitment to test hypotheses relevant to biodiversity conservation. A general guideline is to proceed from the top down, beginning with a coarse-scale inventory of landscape pattern, vegetation, habitat structure, and species distribution, then overlaying data on stress levels to identify biologically significant areas at high risk of impoverishment. Intensive research and monitoring can be directed to high-risk ecosystems and elements of biodiversity, while less intensive monitoring is directed to the total landscape (or samples thereof). In any monitoring program, particular attention should be paid to specifying the questions that monitoring is intended to answer and validating the relationships between indicators and the components of biodiversity they represent." (Author's abstract).

INDEX OF BIOLOGICAL INTEGRITY (IBI):

• Fausch, K. D., J. Lyons, J. R. Karr, and P. L. Angermeier. 1990. Fish Communities as Indicators of Environmental Degradation. American Fisheries Society Symposium 8: 123-144.

The authors advocate the use of biological monitoring of fishes to assess environmental degradation, arguing that the relative health of a fish community is a sensitive indicator of direct and indirect stresses on the entire aquatic ecosystem. They critique the "most common approaches to such assessment of environmental degradation: (1) indicator taxa or guilds; (2) indices of species richness, diversity, and evenness; (3) multivariate methods; and (4) the index of biotic integrity (IBI)." They cite advantages and disadvantages to all four approaches. They suggest that "future research in biological monitoring by means of fish communities should focus on (1) standardization of methods of sampling and data analysis; (2) documentation of natural variation in fish communities, against which changes due to degradation can be compared; and (3) experimental manipulation to test assumptions underpinning all the indices."

• Karr, J. R. 1987. Biological Monitoring and Environmental Assessment: a Conceptual Framework. Environmental Management 11(2): 249-256.

"Direct biological monitoring is essential for effective assessment efforts. Past approaches to biomonitoring are too simplistic (for example, toxicity testing, indicator species) or conceptually invalid (diversity indexes). Assessments that use ecological guilds use ecological principles in a more integrative fashion. The best long-term approach is development of suites of metrics, like those used in the index of biotic integrity (IBI), to reflect individual, population, community, and ecosystem attributes in an integrative framework. Efforts to use the conceptual content of IBI in a wider diversity of habitats should be encouraged and followed up with effective control actions." (Author's abstract).

• Karr, J. R. 1991. Biological Integrity: A Long-Neglected Aspect of Water Resource Management. Ecological Applications 1(1): 66-84.

"Water of sufficient quality and quantity is critical to all life. Increasing human population and growth of technology require human society to devote more and more attention to protection of adequate supplies of water. Although perception of biological degradation stimulated current state and federal legislation on the quality of water resources, that biological focus was lost in the search for easily measured physical and chemical surrogates. The "fishable and swimmable" goal of the Water Pollution Control Act of 1972 (PL 92-500) and its charge to "restore and maintain" biotic integrity illustrate that law's biological underpinning. Further, the need for operational definitions of terms like "biological integrity" and "unreasonable degradation" and for ecologically sound tools to measure divergence from societal goals have increased interest in biological monitoring. Assessment of water resource quality by sampling biological communities in the field (ambient biological monitoring) is a promising approach that requires expanded use of ecological expertise. One such approach, the Index of Biotic Integrity (IBI), provides a broadly based, multiparameter tool for the assessment of biotic integrity in running waters. IBI based on fish community attributes has now been applied widely in North America. The success of IBI has stimulated the development of similar approaches using other aquatic taxa. Expanded use of ecological expertise in ambient biological monitoring is essential to the protection of water resources. Ecologists have the expertise to contribute significantly to those programs." (Author's abstract).

• Miller, D. L., P. M. Leonard, R. M. Hughes, J. R. Karr, P. B. Moyle, L. H. Schrader, B. A. Thompson, R. A. Daniels, and K. D. Fausch. 1988. Regional applications of an index of biotic integrity for use in water resource management. Fisheries (Bethesda) 13(5): 12-20.
"The index of biotic integrity (IBI) integrates 12 measures of stream fish assemblages for assessing water resource quality. Initially developed and tested in the Midwest, the IBI recently was adapted for use in [several other regions]. The concept also was extended to Louisiana estuaries. In regions of low species richness, the IBI proved difficult to apply and often required extensive modification. Adapting the IBI to those regions required that metrics be replaced, deleted, or added to accommodate regional differences in fish distribution and assemblage structure and function. Frequently replaced metrics include: proportion of individuals as green sunfish (*Lepomis cyanellus*), proportion of individuals as insectivorous cyprinids, proportion of individuals as hybrids, and number and identity of sunfish and darter species. The proportion of individuals as top carnivore metric was often deleted. Metrics added include total fish biomass and the number and identity of minnow species. These modifications generally followed the original IBI concept and its theoretical underpinnings. Problems remain in establishing tolerance rankings and scoring criteria, and adjusting scoring criteria for gradient differences in streams of similar size. The IBI holds promise for direct biological monitoring because of its strong ecological foundation and flexibility. ... The IBI thus serves as a quantitative, biological goal for water resource management." (Authors' abstract, shortened.).

ECOSYSTEM MANAGEMENT:

• Grumbine, R. E. 1994. What is ecosystem management? Conservation Biology 8(1): 27-38.
"The evolving concept of ecosystem management is the focus of much current debate. To clarify discussion and provide a framework for implementation, I trace the historical development of ecosystem management, provide a working definition and summarize dominant themes taken from an extensive literature review. The general goal of maintaining ecological integrity is discussed along with five specific goals: maintaining viable populations, ecosystem representation, maintaining ecological process (i.e., natural disturbance regimes), protecting evolutionary potential of species and ecosystems, and accommodating human use in light of the above. Short-term policy implications of ecosystem management for several groups of key actors (scientists, policy makers, managers, citizens) are discussed Long-term (gt 100 years) policy implications are also reviewed including reframing environmental values, fostering cooperation, and evaluating success. Ecosystem management is not just about science nor is it simply an extension of traditional resource management; it offers a fundamental reframing of how humans may work with nature." (Author's abstract).

• **Slocombe, D. S. 1993. Implementing Ecosystem-based Management. Bio Science 43(9): 612-622.**
"This article reviews and synthesizes theory and practice that facilitate implementing ecosystem-based management. It links insights from ecology and other sciences with experience derived from case-studies of regional environmental planning and management. And it is intended to contribute to improving regional-scale planning and management of broadly defined ecosystems-coherent, self-defined, and self-organizing units comprising interacting ecological, economic, and social components." (Taken from the text).

RESTORATION:

• **Berger, J. J., ed. 1990. Environmental Restoration: Science and Strategies for Restoring the Earth. Washington, D.C.: Island Press.**
"This volume is a result of a four-day national conference on ecological restoration, held to consider the restoration of all major natural resource systems and the planning of environmentally sustainable urban areas. It consists mainly of the scientific and technical portion of the conference and is divided in three principal parts, treating aspects of (1) terrestrial restoration, (2) aquatic restoration, and (3) law, planning, land acquisition, and conflict resolution, all as related to restoration. A list of general references is provided at the end of the book, and an appendix contains information about obtaining portions of the conference not included in this book." Especially: Silverman & Meiorin (*Seasonal Freshwater Wetland Development in South San Francisco Bay*). (Taken from the preface).

• **Gore, J. A., ed. 1985. The Restoration of Rivers and Streams: Theories and Experience. Boston, MA: Butterworth Publishers.**
"... I have attempted to collect works by biologists, hydrologists, engineers, and other stream managers working in the field. The body of the material presented in this book represents the theory and experience of academicians and stream managers who have attempted to establish criteria and standards for a great variety of restoration projects. This book is intended to display theories, experiences, and techniques that have proven to be of good use in enhancing the recovery of damaged running water ecosystems. A wieldy volume of information cannot necessarily be comprehensive. Most of the case studies presented here emphasize large impacts from surface mining. Yet many of the same techniques can easily be applied to mitigation of impacts from highway and bridge construction and agricultural channelization. The stream manager using these works must be able to wisely employ needed measures on a site-specific basis. ..." (Taken from the introduction).

• **Gore, J. A. and F. D. Shields Jr. 1995. Can Large Rivers Be Restored? BioScience 45(3): 142-152.**
The authors provide an overview of large river restoration because "restoration and rehabilitation projects for large river systems are far less common [than for small streams and rivers]." The paper suggests that large river rehabilitation requires some combination of placement of vegetation, development of structures (such as dikes and artificial riffles), action to ameliorate floodplain isolation, and remediation of water-quality degradation. Sections include *River Channel Manipulations, Riparian Zone and Floodplain Alterations, Flow Regulation*, and *Predicting Recovery Rates*. The authors argue that renewal of physical and biological interactions between the main channel, backwaters, and floodplains is central to rehabilitation.

• **1995. Entire issue- Special Section: Ecology of Large Rivers. BioScience 45(3).**

• **National Research Council. 1992. Restoration of Aquatic Ecosystems: Science, Technology, and Public Policy. National Academy Press: Washington, D.C.**
"Ecosystem restoration, at any size scale, is a complicated and expensive process. Restoration requires a return to a pre-disturbance condition involving both physical form and natural, self-regulatory function. This text presents a highly detailed review of restoration priorities and possibilities regarding freshwater ecosystems, specifically lakes, streams, rivers, and wetlands. Carrying the weight of the National Academy of Sciences (a non-profit, non-governmental society mandated to provide scientific advice (both solicited and unsolicited) to the federal government). This text both reviews a variety of case-studies in aquatic restoration and provides specific guidelines for future efforts. Topics include a history of changing goals, planning and evaluating, integrated restoration, and a national restoration strategy. The text is illustrated, heavily referenced, and indexed." (Author's abstract).

CASE STUDIES:

• **1995. Entire- Special Issue: Kissimmee River Restoration. Restoration Ecology 3(3).**

• **Davis, S. M. and J. C. Ogden, eds. 1994. Everglades: The Ecosystem and Its Restoration. Delray Beach, FL: St. Lucie Press.**
"This text examines the past and present ecological conditions within Florida's Everglades. The main purpose of the text is to examine the hydrologic, vegetative, terrestrial, and organismal interrelatedness that occurs within this ecosystem. It is proposed that the answers to the restoration of the Everglades will be discovered within this ecological connection. The text consists of thirty-one chapters which are organized into five main sections. The everglades issues in a broader perspective, spatial and temporal characteristics of ecosystem driving forces, vegetation components and process, faunal components and processes, and toward ecosystem restoration are the section headings. Each chapter is individually authored and contains its own reference list. Supplementing the text are tables, graphs, diagrams, maps, and an extensive index." (Authors' abstract).

• **Gunderson, L. H., S. S. Light, and C. S. Holling. 1995. Lessons from the Everglades. BioScience Supplement: S 66-S 73.**
"The history of water management in the Everglades is a useful test case for lessons learned on policy, science, and management. We begin with a summary of how the ecosystem has changed during this century. The history of water management is composed of four eras in which science and scientists played key roles in the transformation between each of the eras. We use the history of water deliveries to Everglades National Park as a more detailed example of how science, policy, and politics interact. Then we present some theoretical propositions to describe key roles played by scientists and technical experts." (Taken from the introduction).

• **Kern, K. 1992. Restoration of Lowland Rivers: the German Experience. Pages 279-297 *in* Carling, P. A. and G. E. Petts, eds. Lowland Floodplain Rivers: Geomorphological Perspectives. John Wiley & Sons, Ltd.: New York, NY.**
This paper provides background information about restoration of lowland rivers in Germany, with case studies of the Upper Rhine and Upper Danube rivers. Management and studies are discussed in three major components: river bed, floodplain, and tributaries, and the 'Leitbild' (or 'guiding image') concept is explored as a planning principle.

• **Toth, L. A. 1993. The Ecological Basis of the Kissimmee River Restoration Plan. Florida Scientist 56(1): 25-51.**
"This review synthesizes over 40 years of studies on the ecological resources of the Kissimmee River. Prior to 1962 the Kissimmee River ecosystem supported diverse fish and wildlife populations including waterfowl, wading birds, and a nationally recognized fishery. The historic floodplain consisted of a mosaic of broadleaf marsh, shrub and prairie wetland communities. Between 1962 and 1970 the river was channelized and transformed into a series of impounded reservoirs. The physical impacts of channelization, including alteration of the system's unique hydrologic characteristics, largely eliminated the wetland and fish and wildlife values of the river and floodplain. Attendant "restoration" studies, including the recently completed demonstration project which documented habitat, water quality, avian, fish and vertebrate responses to water level manipulations, reestablished floodplain inundation, and reintroduced flow, confirmed the feasibility of restoring both the structure and functions of the historic Kissimmee River ecosystem. The integration of available data on pre-channelization resources, impacts of channelization, and restoration-related studies forms the basis of the current plan to restore the ecological integrity of the Kissimmee River." (Author's abstract).

• **Toth, L. A., J. T. B. Obeysekera, W. A. Perkins, and M. K. Loftin. 1993. Flow Regulation and Restoration of Florida's Kissimmee River. Regulated Rivers: Research and Management 8: 155-166.**
"Channelization of the Kissimmee River in central Florida destroyed or degraded most of the fish and wildlife habitat once provided by the river and its floodplain wetlands. Between 1984 and 1989 a demonstration project was conducted to evaluate the feasibility of restoring the river's biological resources. Reintroduction of flow through remnant river channels improved river channel habitat diversity and led to favorable responses by fish and invertebrate communities. However, results indicated that more complete restoration of biological attributes will require the re-establishment of historical inflow characteristics. Owing to the flood control regulation schedule of its headwater lakes, current river discharge regimes are pulse-like, include extended periods of low or no flow, and have high and low flow periods which are out of phase compared with typical seasonal patterns that occurred before channelization. These flow characteristics will preclude effective river restoration by contributing to chronic low dissolved oxygen regimes and repetitive fish kills, interfering with fish reproduction and limiting floodplain inundation. Simulation modeling was used to develop a modified headwater lakes regulation schedule which re-establishes season flow patterns, smoothes discharge peaks and maintains base flows for a greater portion of the year. Implementation of the new schedule, combined with extensive canal backfilling, will lead to discharge and stage characteristics that meet established criteria for achieving ecosystem restoration goals." (Authors' abstract).

<u>SAN FRANCISCO BAY-DELTA-RIVER ECOSYSTEM:</u>

• **Berger, J. J., ed. 1990. Ecological Restoration in the San Francisco Bay Area: A Descriptive Directory and Sourcebook. Berkeley, CA: Restoring the Earth.**
" ... This directory is intended to facilitate the sharing of technical, managerial, and practical information among restorationists.... The directory contains eight chapters which discuss the restoration of various ecotypes. Each chapter begins with an in-depth study of a project that succeeded in restoring native habitat and which included public involvement and education. Following the in-depth report are brief project descriptions, with a map indicating their locations. ... The projects include restoration of salt-, fresh-, and brackish-water wetlands urban and rural creeks; lakes; watersheds; wildlife habitats; mined lands; forests; grasslands; as well as coastal and riparian areas. ... ". (Taken from the introduction).

• **Jassby, A. D., W. J. Kimmerer, S. G. Monismith, C. Armor, J. E. Cloern, T. M. Powell, J. R. Schubel, and T. J. Vendlinski. 1995. Isohaline position as a habitat indicator for estuarine populations. Ecological Applications 5(1): 272-289.**

"....Decreased river inflow due to drought and increased freshwater diversion have contributed to the decline of at least some populations of aquatic organisms in the San Francisco Bay/Sacramento San Joaquin Delta Estuary ('Bay/Delta). Effective management of the estuary's biological resources requires a sensitive indicator of the response to freshwater inflow. ... Positioning of the 2 ‰ (grams of salt per kilogram of seawater) bottom salinity value along the axis of the estuary was examined for this purpose. The 2 ‰ bottom salinity position (denoted by X_2) has simple and significant statistical relationships with annual measures of many estuarine resources. ... X_2 also satisfies other recognized requirements for a habitat indicator and probably can be measured with greater accuracy and precision than alternative habitat indicators such as net freshwater inflow into the estuary. The 2 ‰ value may not have special ecological significance for other estuaries ..., but the concept of using near-bottom isohaline position as a habitat indicator should be widely applicable. Although X_2 is a sensitive index of the estuarine community's response to net freshwater inflow, other hydraulic features of the estuary also determine population abundances and resource levels. In particular, diversion of water for export from or consumption within the estuary can have a direct effect on population abundance independent of its effect on X_2. The need to consider diversion, in addition to X_2, for managing certain estuarine resources is illustrated using striped bass survival as an example. The striped bass survival data were also used to illustrate a related important point: incorporating additional explanatory variables may decrease the prediction error for a population or process, but it can increase the uncertainty in parameter estimates and management strategies based on these estimates. Even in cases where the uncertainty is currently too large to guide management decisions, an uncertainty analysis can identify the most practical direction for future data acquisition." (Authors' abstract, shortened).

PERTINENT INTERNET SITES:

http://bard.wr.usgs.gov/access/access_sfb.html
http://bard.wr.usgs.gov/access/SFB_Biblio.html
http://www.regis.berkeley.edu/baydelta.html
http://www.regis.berkeley.edu/index.html
http://www.abag.ca.gov/bayarea/enviro/enviro.html
http://www.abag.ca.gov/bayarea/sfep/sfep.html
http://www.delta.dfg.ca.gov/
http://www.delta.dfg.ca.gov/baydelta/monitoring/monitor.html
http://www.epa.gov/emap/index.html
http://www.epa.gov/nep/nepbroc.html
http://earth1.epa.gov/nep/
http://ice.ucdavis.edu/Center_for_Ecological_Health_Research/San_Francisco_Bay-Delta_Model.html
http://ice.ucdavis.edu/California_Rivers_Assessment/related_information_sources.html
http://ice.ucdavis.edu/California_Watershed_Projects_Inventory

APPENDIX A-3:
OCTOBER WORKSHOP AGENDA

Restoration of the San Francisco Bay-Delta-River: Choosing Indicators of Ecological Integrity

Saturday, October 28, 1995

California Alumni House
University of California, Berkeley
Berkeley, CA

Workshop Agenda

8:15 **Morning Coffee, Juice, Bagels**

8:30 **Welcome, Introductions, and Review of Workshop Agenda**
Bill Alevizon, The Bay Institute of San Francisco (15-18 mins)
David Zilberman, UCB Center for Sustainable Resource Development (CSRD) (12-15 mins)

9:00 **Opening Address**
Choosing Indicators of Ecological Integrity
Dr. Paul Keddy, Professor of Biology, University of Ottawa (40 mins)
(Questions for Dr. Keddy - 10 min)

9:50 **Speaker and Discussion**
Developing a Bay-Delta Management Policy: Identifying Goals and Objectives
Dick Daniel, CALFED Bay-Delta Program (15 min presentation, 35 min discussion)

10:45 **Break**

11:00 **Case Study Panel Discussion**
Identifying Ecological Indicators for Restoration of Aquatic Ecosystems: Lessons Learned
Kissimmee River - Lou Toth, Supervisory Professional, Kissimmee River Basin Division, South Florida Water Management District
Mississippi River - Charles A. Simenstad, Coordinator, Wetlands Ecosystem Team, School of Fisheries, University of Washington
Rhine River - Hans Bernhart, Deputy Director, Institute of Hydraulic Structures and Agricultural Engineering, University of Karlsruhe
(Moderator: Bill Alevizon, Bay Institute, Questions 20 mins)

Workshop Agenda (cont'd)

12:30 Buffet Lunch

1:15 Bay-Delta Panel

Indicators Applicable to the S.F. Bay-Delta-River Ecosystem
Philip Williams, President, Philip Williams & Associates Ltd.
Peter Moyle, Professor Wildlife And Fisheries, UCD
Josh Collins, Environmental Scientist, San Francisco Estuary Institute
Zack Powell, Professor, Integrated Biology, UCB
Bruce Herbold, Environmental Protection Specialist, Water Management Division, USEPA
Vince Resh, Professor, Environmental Policy, Science & Management, UCB
(Co-Moderators: Rod Fujita, Environmental Defense Fund and Emery Roe, CSRD, Questions 25 mins)

3:10 Break-Out Groups

Review Operational Definitions of Ecosystem Health and Matrix of Ecological Indicators
(Moderators: Gary Bobker, Bay Institute; Rod Fujita, EDF; Chris Dumas, Agricultural and Resource Economics, UCB; refreshments provided)

4:30 Synthesis

5:00 Policy Panel Discussion

Implementation: Policy and Management Perspectives on Candidate Indicators
Dick Daniel and Judy Kelly, CALFED, Bay Delta Program
(Moderator: David Zilberman, Chair, Agricultural and Resource Economics Department, UCB, Questions 10 mins)

5:30 Action Items for Next Workshop

(Bill Alevizon, Bay Institute)

5:45 Reception

This workshop is funded by the U.S. Environmental Protection Agency and is co-sponsored by The Bay Institute of San Francisco, the Environmental Defense Fund, and the Berkeley Center for Sustainable Resource Development

APPENDIX A-4:
DRAFT MINUTES FROM OCTOBER WORKSHOP

SUMMARY MINUTES

WORKSHOP ON "RESTORATION OF THE SAN FRANCISCO BAY-DELTA-RIVER ECOSYSTEM: CHOOSING INDICATORS OF ECOLOGICAL INTEGRITY." OCTOBER 28, 1995

Held at Alumni House, University of California, Berkeley
Sponsored by the US Environmental Protection Agency, Berkeley Center for Sustainable Resource Development, The Bay Institute of San Francisco, and Environmental Defense Fund

IN ATTENDANCE: See attached participants' list.

MINUTES:

I. Introduction

Two EPA-funded workshops, the first of which was held on October 28, 1995 and the second of which is planned for January 25-26, 1996, are intended to provide a conceptual framework and methodologies for developing a set of indicators to guide restoration efforts for the San Francisco Bay-Delta-River ecosystem. The ecosystem is comprised of the watersheds of the Sacramento and San Joaquin Rivers, their delta, and the San Francisco Bay.

The October 28 workshop built upon previously identified operational definitions of ecological integrity for the Bay-Delta-River ecosystem, and sought to learn from the experiences of restoration efforts in other aquatic systems in the US and overseas. A primary objective of the one-day workshop was to better identify and define a suite of scientifically defensible indicators that would, in concert, be a useful tool in assessing the health or integrity of the system. A common basis and language for defining ecological indicators would also be developed through this process.

The efforts of the October 28 workshop corresponded to the first two steps in the four-step process recommended by Dr. Paul Keddy of the University of Ottawa (the workshop's keynote speaker) as a model for developing relevant ecological indicators:

1. Define health or integrity in an operational way.
2. Select indicators of health or integrity.
3. Identify target levels or desired ranges for relevant indicators.
4. Develop a monitoring system to provide feedback on changes in indicator levels over time.

While substantial progress on Steps 1 and 2 was achieved at the first workshop, remaining tasks for our project primarily include (1) working towards completion of Step 2 (i.e., finalizing a recommended list of indicators) and (2) beginning the process of developing a sound process and methodology for undertaking Step 3 (identification of target ranges). It would appear that Step 4 (developing a monitoring program) would logically follow from completion of Steps 1-3, probably under the auspices of the revised IEP program.

II. Workshop Highlights

Setting the Stage (morning presentations)

• *David Zilberman, Faculty Director of the UCB Center for Sustainable Resource Development,* opened the workshop by briefing the participants on the Center and the long involvement of UCB faculty and researchers with California water issues, including those of the Bay-Delta. He went on to stress the importance of transparency, trade-offs and research to the Bay-Delta planning exercise, particularly that of CALFED. The planning process must be transparent, trade-offs between competing objectives should be identified in a quantifiable, measurable fashion, and the lack of optimum research in core areas will have to be recognized and responded to from the outset.

• *Bill Alevizon, of The Bay Institute of San Francisco and the UCB Geography Department,* followed by laying out the rationale for the workshop and why the participants were there. He also stressed the need for indicators that focus on the measurable attributes of the ecosystem. Thus, indicators should measure the performance of the ecosystem and progress made in restoring the Bay-Delta-River ecosystem. He raised several areas that would have to be addressed when defining a suite of suitable indicators: the utility of population level as distinct from community or habitat level indicators derived from emergent properties of the ecosystem itself as distinct from those derived from societal values; and whether restoration goals should be aimed at creating a self-sustaining ecosystem rather than a highly-managed ecosystem. He emphasized that the purpose of this workshop was to develop indicators for environmental restoration <u>only</u>, not for all of the other CALFED objectives.

• *Dr. Paul Keddy, Professor of Biology, University of Ottawa,* gave the keynote speech, a summary of which will be in the final Proceedings of the two workshops. His main points included:

* Focus on the future and identify indicators at the ecosystem as well as the population levels. Indicators should be simple, preferably with off-the-shelf technology. The planning horizon, for which the indicators would be developed, should be intermediate and long-term as well.

* As for the criteria for indicator selection, indicators should be: (1) important, (2) cheap, (3) macroscale, (4) already available, and (5) necessary. Important means the indicators measure key functions of production and habitat. Cheap means simple, i.e., efficient. Macroscale signifies the bigger the scale, the better the monitoring of the system concerned, other things being equal. Already available means using indicators such as fish production, which already have good time series information, notwithstanding the fact that such information is not perfect. Necessary means some indicators are important because of their constituencies, rather than because of the ecosystem per se.

* Indicators can either measure the key controlling factors in the ecosystem, or, alternatively, their consequences as key properties of those ecosystems. In the first instance, environmental constraints are measured, such as hydrology, fertility, disturbance, and salinity. In the second instance, the key properties arising from these constraints are measured, such as biomass production, species diversity and functional types. In most cases, both types of indicators are needed. Wetlands were discussed as an example.

In the question and answer period, one suggestion was that the area devoted to salt marsh might be a simple, but effective measure of ecosystem health. It was a macroscale variable that could be followed over time from, e.g., air photos.

• *Dick Daniel, Assistant Director for Habitat Restoration, CALFED Bay-Delta Program,* provided background information and the timeline for the CALFED process. In particular, he discussed the CALFED Ecosystem Quality Objective: "Improve and increase aquatic and terrestrial habitats and improve ecological functions in the Bay-Delta to support sustainable populations of diverse and valuable plant and animal species." To this end, his points included:

* The importance of the current challenge to combine water quality objectives of X2 with those objectives for ecosystem management in order to produce a simple, scientifically defensible, *and* fundable program for dealing with CALFED problemshed areas associated with the Delta. This means answering or being prepared to answer a host of questions, including but not limited to: what are we trying to achieve with our endangered species--how many and which ones need be addressed; what do we mean by "shallow, shaded riverine habitat," and how do we measure it--how deep, how saline, how does it change, where is it to be located; and what sort of wetlands do we want?

* He raised a hypothesis which he hoped workshop participants would address: "The restoration of habitat functions can reverse or offset impacts caused by water exports, flood control, land use practices, introduced species, and toxic pollutants." That is, can the ecosystem be restored back to natural? Can it be done without jeopardizing land, property and life? Can we overcome the impacts of urbanization, pesticides and other impinging factors on ecosystem quality and services? Can natural functions be introduced that help cleanse the system of pollutants and other contaminants?

* Daniel concluded by pointing out that the CALFED ecosystem management focus was to be habitat-based. Thus, continued validation of that concept was needed particularly as it is difficult to define just what "habitat" is. Complicating factors include the issue of how much can be restored at a feasible cost and the question of whether it would be "restored" to make it look natural or to make it work harder, i.e. wetlands made to work harder do not necessarily look "natural".

Points raised in the question and answer period kept coming back to the issue of "If we build it, will they come?" If we restore habitat, will the desired species populations thereby be increased and/or preserved? It was suggested that the ecosystem here would have to be "custom-made", as the continuing introduction of exotic species is constantly inventing a new ecosystem. Another point was that the challenge of restoring ecosystems must also include the challenge of restoring ecosystem *processes*. Eco-fixes are not enough.

Three Case Study Presentations

- *Kissimmee River - Lou Toth, Supervisory Professional, Kissimmee River Basin Division, South Florida Water Management District.* A summary of the case presentation will be included in the final Proceedings of the two workshops. In the course of his remarks, Toth described the background to, and evolution of, the Kissimmee restoration efforts, including:

* Restoration goals had started from the specific and evolved into the general. The more general goals also focused on emergent properties of the ecosystem--e.g., resilience and persistence--which transcend "optimum," possibly conflicting levels of various species. De-channelization had become a centerpiece, within the context of mimicking a historic river system that was self-sustaining.

* A field demonstration project had been instrumental in extending the restoration efforts, and a series of indicators and quantified objectives had been put into place to measure the success of these extended efforts. Implementation had occurred through a series of phases, the first being developing conceptual models; the second, establishing target reference conditions (from historical or pristine bases) for achieving restoration; the third, developing baseline conditions of where the system is currently; the fourth being a 15-year construction phase which would track progress made in moving from baseline to target conditions; fifth, construction impact modeling; sixth, restoration response evaluation; and seventh, adaptive management.

- *Mississippi River - Charles A. Simenstad, Coordinator, Wetlands Ecosystem Team, School of Fisheries, University of Washington.* Dr. Simenstad summarized this work on an independent assessment team of a Mississippi Delta restoration project. Some of the team's important findings were:

* Need to look at hydrologic restoration of, e.g., wetlands, on a much broader scale, namely, the regional or watershed level. Wetlands are not self-sustaining systems in this instance, as they are continually being altered in light of changes in sedimentation and other factors originating outside the wetlands ecosystem themselves. (Only some 30% of the loss of wetlands there was due to anthropogenic causes.) In this way, if the effort was to restore Delta wetlands, efforts would have to be made at the upper end of the relevant basins to restore sedimentation flows. Otherwise, marshland restoration would be a doomed technology in this case.

* One of the important lessons for the Pacific Northwest learned from the Mississippi restoration case was that restoration efforts have to be predicated on an understanding of temporal and spatial scales of processes that drive (in this case) wetland maintenance; the regional scale of disturbance is critical.

- *Rhine River - Hans Bernhart, Deputy Director, Institute of Hydraulic Structures and Agricultural Engineering , University of Karlsruhe.* Dr. Bernhart presented a case study that showed the magnitude of the problems faced in restoring some of the flood control potential of the Rhine River, not least of which are density of surrounding population and river transportation requirements. Extinction rates were high as well. His points included:

* It was not possible to "design" a river's meanders, but rather the parameters in which such meanders could take place.

* The restoration efforts were still in their early stages, with modeling and some demonstration work undertaken so far. Preliminary indications from one project, where channelization structures were removed, and a meander allowed to re-establish itself, are encouraging.

Afternoon Experts' Panel

Bay-Delta resource managers, biologists, resource economists and policy analysts were asked to comment on the applicability of the preceding presentations, particularly on how concepts and experiences derived from other ecosystems could be applied to the Bay-Delta-River ecosystem.

- *Philip Williams, President, Philip Williams & Associates Ltd.,* provided a presentation on the template (rather than engineered) approach to restoration--in this case using the concept of physical integrity as the basis of Bay-Delta restoration:

* For any given watershed, the landscape and ecosystem are in geomorphic evolution. Biota have adapted and evolved, e.g. Oregon Coast. As for the Bay-Delta, it has been dominated by erosion. Here, the physical process drives biological process.

* Two ways to look at system restoration: 1) look at undisturbed system; or alternatively 2) look back in time to get an understanding of key physical processes to which biota have adapted within the system of interest. For example, one could look t Willamette River for guidance on the Bay-Delta-River system. A range of other examples are available, including but not limited to the Wildcat Creek restoration project combined with flood management. Levee breaches and other mishaps can serve as natural experiments to see how ecosystems respond to the restoration of more natural hydrologic processes

- *Bruce Herbold, Environmental Protection Specialist, Water Management Division, USEPA,* underscored the need to distinguish between what he called diagnostic and prescriptive indicators. The former lets us know that something's wrong and the latter indicates what can be done to correct it. Diagnostic indicators are by definition not open to manipulation and should be easily measurable (e.g., angler satisfaction, number of striped bass, percentage of idle commercial fishing boats). Prescriptive indicators should be quantifiable and linked to ecosystem processes that could in fact be manipulated and managed (e.g., increasing wetlands, increase spawning habitat, controlling salinity). He gave several examples. He also stressed that the indicators selected should cover the broadest array of targets and be easily adjusted as new information comes in.

- *Peter Moyle, Professor, Wildlife And Fisheries, University of California, Davis,* touched on a number of points--the need to manage better for the future of the ecosystem we now have; we can't go back to older systems; and we must have goals that would, among other things, strive to:

  * ensure no more loss of native species, whether fish or vertebrates;
  * ensure no more invasion of exotic species (e.g., Japanese clam or zebra mussel);
  * have some indicators based on our current knowledge of key fish populations;
  * eliminate or reduce preventable disasters (e.g., collapse of levees); and
  * ensure more and more ships have effective treatment of ballast.

  What was desired was an ecosystem with environmental parameters that kept activities within predictable levels. Our indicators have to be sufficient to answer, "Are we better off than we were before?"

- *Zack Powell, Professor, Integrative Biology, University of California, Berkeley,* talked about the X2 standard and the need and role of models that provided a degree of tolerance to natural variability and unpredictability in the ecosystem. To use an analogy, in much of the Bay-Delta system, what is needed is less a new car than new wheels and brakes. If the engine, transmission, and rear end are in good working order, keep the car and try to fix the problems. The ecosystem is not irretrievably broken, but is definitely in need of repair and, in some places, rebuilding.

• *Vince Resh, Professor, Environmental Science, Policy and Management, University of California, Berkeley,* stressed the need to think of restoration in the context of what can be done with reduced or diminishing supplies of water. Hydrology is a definite limitation on restoration, given the rising demands for alternative uses of

* Be careful of the term "restoration." In many cases, what is really being talked about everything but "restoration," e.g., improvement, enhancement, rehabilitation and amelioration.

* In view of the water constraints, some experimental restoration approaches should be undertaken concurrently with thinking about indicators. For example, our understanding of the pulse flow concept as a way of managing river systems using less water came about due to research.

* One of the problems that we have with introduced species getting established so readily is the fact that the niches are either unfilled or very broad. As the Bay is relatively young, the strategy of improving habitat is not going to rid of exotic species as they are there because of these unfilled niches.

• *Josh Collins, Environmental Scientist, San Francisco Estuary Institute,* focused the participants on what is achievable, given our understanding of natural ecosystems. (To this end, he mentioned the SFEI Estuary Project which could be seen as complementing the CALFED process.) Increased understanding, in turn, should provide a useful context for policy making. He endorsed the need for a classification or typology of habitats in the Bay-Delta-River ecosystem. He raised several other issues , including: the past ecosystem need not be a model for the future system, as restoration goals will always be revised in light of new understanding of ecosystems; the need for an "ecological health board," which would indicate where restoration efforts are working and where we need better ecosystem health; and the shift from population to community variables and indicators. There are no absolutes in setting goals and objectives; there should be no planning horizon per se; and the goals should be based on three kinds of understanding: understanding of the past, understanding of the present; and an understanding of change.

Synthesis of the Four Break-Out Groups: Bulleted Points

Four break-out groups were formed in order to identify relevant ecological indicators for Bay-Delta-River ecosystem health. The following is a summary of their presentations:

- *Group A (Lou Toth, Facilitator and Presenter)*

  * <u>Issues to Consider in Choosing Candidate Indicators</u>

    Several "categories" of indicators are needed:
    -Structural: e.g.: pop levels, community types and levels, habitat characteristics;
    -Functional; e.g. physical processes, primary production.

    Again, indicators should be scientifically defensible. Various spatial and temporal scales must be accommodated, including some "quick response" indicators.

    We should have a "suite" of several indicators within each category, recognizing that target levels for the indicators may well change over time nd that ecological succession in the Bay-Delta system may be highly attenuated (i.e., indicators based on succession may not be appropriate).

  * <u>Specific Candidate Indicators</u>

    1) diversity of bathymetry (at various scales: landscape, watershed, marsh)
    2) spatial extent of various habitat types
    3) miles of edge habitat
    4) density of avian species (number of species per acre) by habitat type
    5) commercial/recreational fisheries indicators:
       availability of requisite habitat types for spawning, rearing, passage;
       population sizes of selected fish species;
       annual escapement of selected fish species.
    6) percent of population of selected species taken at the Delta water export pumps
    7) water flux between open water and wetland habitats
    8) carbon flux between open water and wetland habitats
    9) C-14 uptake in open water habitats
    10) structure of benthic invertebrate communities (perhaps by functional guilds) in open water habitat
    11) make use the X2 isohaline index (*strong support for this index in group*)
    12) changes in sediment loading and transport rates
    13) smolt survival in freshwater habitats
    14) reestablish distribution (spatial and temporal) of rare and endangered species

- *Group B (Si Simenstad, Facilitator and Presenter)*

* Issues to Consider in Choosing Candidate Indicators

Indicators need to be ranked & evaluated in accordance with Keddy's criteria. The group also added their own criteria for indicator selection, i.e., the indicator should be mechanistic, amenable to adaptive management, responsive to changes in the ecosystem; and quantifiable.

Also: a) ensure each scale is covered within the "hierarchy of scale" (both spatial and temporal) of potential indicators.
b) try to identify relationships among indicators across scales.
c) classification for habitat types should represent various functional scales.
d) each habitat type should be quantified.
e) the *structure* of habitat within areas should be indexed.
f) also need a *functional* measure within each habitat type. e.g.: biological condition.
g) need *composite* indices composed of several indicators, not single indicators.
h) need demonstration/pilot projects to test/refine/and *learn more* about candidate indicators. e.g.: "IBI's"

* Candidate Indicators (each includes several more specific indicators)

1) Acreage of each habitat type within each geographic region of the Bay-Delta-River Continuum
2) Landscape form indices related to habitat function
3) Index of habitat health
4) Composite measure of biological condition

- *Group C (Bill Alevizon, Facilitator and Presenter)*

    * Candidate Indicators
        1) Number of acres of habitat types governed mainly "natural processes" vs. number of acres dominated by "human uses"
        2) Contaminant concentrations. e.g.: organophosphate concentrations
        3) Total area and proportion of key habitat types
        4) Amount of critical habitat available to key fish species
        5) Measure of gravitational circulation/extent to which it occurs, as indicator of water mixing
        6) Water temperature
        7) Total acres of wetlands
        8) Measures of exotics
        9) Number of native fish populations below threshold levels
        10) Measure of net carbon budget
        11) Distribution of biomass among trophic levels
        12) Measure of primary production
        13) Tidally inundated habitat area
        14) Length of natural tidal banks and bank diversity
        15) Area inundated by one or two-year floods
        16) Frequency of flood flows
        17) Deviations from natural season patterns

• *Group D (Paul Keddy, Facilitator and Presenter)*

* Issues to Consider in Choosing Candidate Indicators

Ensure coverage of 6 categories of indicators:
critical habitat; watershed hydrology; pollution & fertility; sediment; species diversity; and human population

Candidate Indicators

Spatial measures (e.g. acreage) of critical habitat types:

1) Mudflats (intertidal)
2) Shallow water
3) Salt marsh (tidal)
4) Freshwater marsh
5) Vegetated creek (miles or km)
6) Low salinity open water
7) Submerged aquatic vegetation

Diversity:

8) Measures of diversity, including those for invertebrates and plants
9) Number of exotics
10) Indices for migratory waterfowl, algae, invertebrates

Hydrological indicators:

11) Acreage that is annually flooded
12) Measure of sinuosity or complexity
13) Measure of large water pulses
14) Measure of salinity
15) Measure of pollution. e.g.: concentration, kilometers, or weeks below critical levels or targets
16) Values, concentration in edible species

Sediment indicators:

17) Sediment input
18) Accumulation of organic matter (important indicator as it measures both production and decomposition)

Human-impact indicators:

19) Human population size in watershed
20) Per capita water use in watershed
21) Area of asphalt
22) Area of native vegetation

After the presentation of the four workgroups' ideas, there were a few comments on the current process within the historical context of Bay-Delta restoration efforts. Alex Horne pointed out that a number of indicators for "the health" of the Bay had come and gone. He recommended his own indicator, the percentage of sky darkened by flying species.

Concluding Remarks

- *David Zilberman* reiterated the need for some indicators of human recreation activities, e.g., number of days fishing, that would measure human benefits from the ecosystem services provided by the Bay-Delta-River system.

- *Dick Daniel* once again stressed the need for simple, defensible indicators and ones as manageable as those for X2. He reaffirmed the need for an ecosystem that would be as self-sustaining as possible rather than one that requires ever more human management. He encouraged participants to provide their own indicator recommendations directly to his office. The point was raised that participants could work together in order to consolidate their recommendations.

- Finally, it was agreed that the next workshop would be brought forward to January 25-26. Bill Alevizon concluded by recommending, in his view, the utility of the template approach to restoration and modeling the historical evolution of the ecosystem to obtain insight into critical processes, structures, and target levels of indicators.

Adjournment and Reception

APPENDIX A-5:
LIST OF PARTICIPANTS AT THE OCTOBER WORKSHOP

PARTICIPANTS: Bay-Delta-River Workshop, Saturday, October 28, 1995 - UC Berkeley

first name	last name	affiliation/address	city, state zip
Bill	Alevizon	The Bay Institute of San Francisco, 625 Grand Ave, Ste 250	San Rafael, CA 94901
Betty	Andrews	Philip Williams & Associates Ltd. Pier 35, The Embarcadero	San Francisco, CA 94133
Kathryn	Ankrum	The San Francisco Estuary Project 2101 Webster St., Ste. 500	Oakland, CA 94612
Elaine	Archibald	Archibald & Wallberg Consultants 1604 Potrero Way	Sacramento, CA 95822
David	Behar	The Bay Institute of San Francisco, 625 Grand Ave, Ste 250	San Rafael, CA 94901
Bill	Bennett	UC Bodega Bay Lab P.O. Box 247	Bodega Bay, CA 94923
Hans	Bernhart	University of Karlsruhe, Kaiserstrasse 12, D-76128	Karlsruhe, Germany
Gary	Bobker	The Bay Institute of San Francisco, 625 Grand Ave. Ste 250	San Rafael, CA 94901
Roberta	Borgonova	League of Women Voters, 2480 Union Street	San Francisco, CA 94123
Josh	Collins	San Francisco Estuary Institute 1325 S 46th	Richmond, CA 94804
Pat	Coulston	California Dept of Fish & Game 4001 N Wilson Way	Stockton, CA 94205
Dick	Daniel	CALFED Bay Delta Program 1416 9th Street, Suite 1155	Sacramento, CA 95814
Chris	Dumas	Graduate Researcher, Agricultural & Resource Econ., UC Berkeley	Berkeley, CA 94720
Harrison	Dunning	School of Law UC Davis	Davis, CA 95616
Phyllis	Fox	Consulting Engineer	Berkeley, CA 94704
Rodney	Fujita	Environmental Defense Fund 5655 College Ave. #304	Oakland, CA 94618
David	Fullerton	Natural Heritage Institute 114 Sansome St.	San Francisco, CA 94104
Sharon	Gross	CALFED Bay-Delta Program 1416 9th Street, Suite 1155	Sacramento, CA 95814

PARTICIPANTS: Bay-Delta-River Workshop, Saturday, October 28, 1995 - UC Berkeley

first name	last name	affiliation/address	city, state zip
Andy P.	Gutierrez	135 Giannini Hall UC Berkeley	Berkeley, CA 94720
Ken	Hall	Center for Sustainable Resource Development, UC Berkeley	Berkeley, CA 94720
Chuck	Hanson	Hanson Environmental 132 Cottage Lane	Walnut Creek, CA 94595
Susan	Hatfield	U.S. EPA 75 Hawthorne St.	San Francisco, CA 94105
Bruce	Herbold	U.S. EPA 75 Hawthorne St.	San Francisco, CA 94105
Kathryn	Hieb	California Dept. of Fish and Game 4001 North Wilson Way	Stockton, CA 95205
Alex	Horne	609 Davis Hall UC, Berkeley	Berkeley, CA 94520-1710
Paul	Keddy	University of Ottawa	Ontario, Canada
Judy	Kelly	U.S. EPA 75 Hawthorne St.	San Francisco, CA 94105
Karen	Levy	Environmental Defense Fund 5655 College Ave. #304	Oakland, CA 94618
Jud	Monroe	119 Barber Ave.	San Anselmo, CA 94960
Peter	Moyle	University of California, at Davis	Davis, CA 95616
Fred	Nichols	USGS Middlefield Rd. MS 472	Menlo Park, CA 94025
Zack	Powell	3060 Valley Life Sciences Building, UC, Berkeley	Berkeley, CA 94720-3140
Tim	Ramirez	390 Wurster Hall, UC, Berkeley	Berkeley, CA 94720-1460
Rich	Reiner	Cosumnes River Preserve 13501 Franklin Rd.	Galt, CA 95632
Vince	Resh	305 Wellman Hall UC, Berkeley	Berkeley, CA 94720

PARTICIPANTS: Bay-Delta-River Workshop, Saturday, October 28, 1995 - UC Berkeley

first name	last name	affiliation/address	city, state zip
Pete	Rhoads	Metropolitan Water District Southern California 1121 L Street, Ste 900	Sacramento, CA 95814
Palma	Risler	U.S. EPA 75 Hawthorne	San Francisco, CA 94105
Emery	Roe	101 Giannini, UC, Berkeley	Berkeley, CA 94720
Hsieh Wen	Shen	412 O'Brian Hall, UC, Berkeley	Berkeley, CA 94720-1460
Charles A.	Simenstad	School of Fisheries, University of Washington Box 357980	Seattle, WA 98195-7980
Michael	Thabault	U.S Dept of Fish and Wildlife 2800 Cottage Way, Rm E1803	Sacramento, CA 95825-1846
Lou	Toth	South Florida Water Mgmt. District P.O. Box 24680 3301 Gun Club Rd	West Palm Beach Fl 33416-4680
Ronnie	Weiner	Natural Resources Defense Council 71 Stevenson St.	San Francisco CA 94105
John	Williams	Hydrology and Water Resour. Planning 875 Linden Ln.	Davis, CA 95616
Philip	Williams	Philip Williams & Associates Ltd. Pier 35, The Embarcadero	San Francisco, CA 94133
Leo	Winternitz	Dept of Water Resources Env. Services Office 3251 S Street	Sacramento CA 95816
Diana	Woods	U.S. EPA 75 Hawthorne Street	San Francisco, CA 94105
Terry	Young	Environmental Defense Fund 5655 College Ave. #304	Oakland CA 94618
David	Zilberman	327 Giannini, UC, Berkeley	Berkeley, CA 94720

APPENDIX B-1: WORKING PAPER PREPARED FOR JANUARY WORKSHOP

C-049474

Choosing Indicators of Ecological Integrity: Part Two

WORKING PAPER FOR JANUARY 25-26 WORKSHOP

I. Introduction

Moving towards the second workshop (January 25-26, 1996) on developing a suite of ecological indicators for the Bay-Delta-River system, this paper and the questionnaire which accompanies it is our attempt to get feedback from workshop participants. This document constitutes the first of two working papers, jointly produced by The Bay Institute (TBI) and the Environmental Defense Fund (EDF), in collaboration with the Center for Sustainable Resource Development at U.C. Berkeley (CSRD), and is intended to bridge the gap between the first and second workshops. A second paper is planned for mid-January, about two weeks prior to the convening of the second workshop. The primary objectives of the working papers are to provide a feedback mechanism and to help workshop participants prepare for the next phase of the indicator selection process.

In this paper we briefly review the context of these two workshops and the results of the October workshop, and then go on to identify our tasks for the January workshop. October workshop breakout groups and individual participants suggested that a system typology, or classification of habitats, be developed for the Bay-Delta-River system. Thus, we propose here a strawman system typology, intended to facilitate development of an organized suite of indicators. We also propose a framework for choosing indicators, to work in conjunction with the system typology, which incorporates structure and function at several hierarchical scales of ecological organization. In Appendix I we place the indicators proposed at the October workshop into this overall framework, as an example and starting point from which to proceed.

Within the text of this working paper, you will find references to questions included in the attached questionnaire. We hope you will put some thought into answering them (**by January 8**). The questionnaire is intended to elicit your comments in three main areas: (1) the indicator development process and workshop organization; (2) the system typology which we present on page 6-7 of this paper; and (3) an evaluation of the indicators proposed at the October 28, 1995 workshop.

II. Background

The December 15, 1994 Bay-Delta Accord, the Central Valley Project Improvement Act (CVPIA), and the establishment of the CALFED Bay-Delta program provide a policy framework for a multi-faceted planning process designed to result in long-term solutions for natural resource use and management of the Bay-Delta-River ecosystem. This system is defined here as the watersheds of the Sacramento and San Joaquin Rivers, their delta, and the San Francisco Bay.

The U.S. Environmental Protection Agency (EPA), in September of 1995, awarded a grant to the CSRD, intended to advance the process of selecting indicators of ecological integrity/health for the ecosystem. TBI and EDF were included in this grant as sub-contractors to U.C. Berkeley, with the responsibility of leading and coordinating the scientific (biological and hydrological) aspects of the project. The core of the project is two workshops focused on choosing ecological indicators for the Bay-Delta-River system, involving local and national technical experts, as well as key resource managers and decision makers involved in Bay-Delta-River environmental issues. This initial EPA grant has been supplemented by funds from the CALFED Bay-Delta Program, in continuation of our efforts.

In this context, ecological indicators are defined as particular measurable properties of the system that are themselves important, or that allow us to evaluate and monitor other system properties (states and processes) that are not directly measurable in themselves, and yet need to be evaluated. Ecological indicators bridge the gap between "real world" science and intuitively desirable but less easily defined and measured ecosystem properties such as "health", "integrity", "resilience" and "self-sustainability".

Indicators allow us to quantify the state of an ecosystem, monitor changes, and evaluate the success (or failure) of particular restoration efforts.

The first workshop was held October 28, 1995, with nearly 50 participants. The primary goals of the workshop were to develop a conceptual framework of ecological integrity and its measurement, and to initiate a process designed to result, by the end of the overall project, in a set of indicators that were mutually developed, and therefore broadly supported, by workshop participants. Participants agreed that the first workshop was generally productive and successful in achieving these goals. All participants should have received by now the minutes of the first workshop, prepared and distributed by the CSRD.[1]

The first workshop was organized according to Keddy et al.'s (1993) recommended four-step process for developing ecological indicators: (1) define ecological integrity or health in an operational way; (2) select appropriate indicators of health or integrity; (3) identify target levels of selected indicators; and (4) develop a monitoring system to provide feedback. We believe the first workshop successfully accomplished the first step, and made a good start on the second. The CALFED ecosystem quality objective statement[2] was generally accepted as an operative mission statement.

The January workshop has the primary goal of refining the framework for developing indicators and completing a provisional list of indicators. During the second workshop, we intend to try to complete, in so far as possible within the limits of this particular project, Step 2 (development of a suite of ecological indicators). While we recognize that the list of indicators provided by this project will doubtless be modified and used in different ways for different purposes, we believe this necessary groundwork will provide a solid and scientifically defensible starting point upon which further efforts

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1 If you have not, please contact Mr. Ken Hall at (510) 643-0585.
2 "Improve and increase aquatic and terrestrial habitats and improve ecological functions in the Bay-Delta to support sustainable populations of diverse and valuable plant and animal species."

might build. Time permitting, we also intend to initiate a discussion of how to go about Step 3 (assigning target values to indicators). We anticipate that step 4 of the Keddy et al. (1993) process (development of an appropriate monitoring program) will be taken up by others, most importantly the Interagency Ecological Program as part of their redesigned long-term monitoring efforts.

This working paper includes and updates, based upon the results of the first workshop, a suggested conceptual framework for developing ecological indicators. Two underlying premises of the framework, supported by the October workshop, are that:

1) indicators should cover both structural and functional components at a variety of hierarchical scales, for the system as a whole as well as for each of its component habitat types and
2) the development of the eventual suite of indicators for the Bay-Delta-River ecosystem requires an open process and a clear and scientifically defensible rationale.

These working papers are intended to help develop a scientifically defensible framework for developing such a comprehensive suite of ecological indicators. (see pp. 7-8)

Additionally, because there was general agreement that the eventual list of recommended indicators needed to be expanded beyond the population-level to include indicators at the landscape-level as well as at lower levels, it became clear that a necessary preliminary step in the process of specifying indicators was to develop a system typology (classification), in order to clearly define the management units for which indicators would be selected. We have proposed a strawman typology below (see pp. 6-7).

Participants at the October workshop seemed to share a common goal of enhancing the self-sustaining qualities of the system, as opposed to moving in the direction of an increasingly highly managed one. The first workshop also pointed out the utility of developing a common vocabulary, allowing a shared clear understanding of the meaning of key terms used frequently throughout our deliberations. To this end, we provide a preliminary glossary (Appendix II). We request that you review this list and provide suggestions for changes or additions.

II. Moving Towards the January Workshop

1. Process

The October workshop provided a solid platform on which to build, including: a background knowledge of other large-scale restoration projects; an initial list of ecological indicators; an initial consideration of criteria appropriate to evaluating and ranking indicators (see Table 1); and a diverse, enthusiastic and knowledgeable group of participants. We suggest that the following four steps are necessary to complete this phase of the project, and should be undertaken between now and the end of the January workshop:

(1) agreeing on an appropriate framework/process to be used to develop the list of ecological indicators;
(2) establishing an appropriate, scientifically defensible system typology;
(3) developing a suite of indicators within habitat types and at all appropriate scales;
(4) initiating discussion of how to go about setting target ranges for the indicators.
***

Towards these ends, we ask for your responses and recommendations to question #1 on the questionnaire.

2. Developing a System Typology

Because of the areal extent and complexity of the Bay-Delta-River system, scale is an important issue in developing a suite of indicators. The October break-out groups discussed the spatial scales indicators should embrace, suggesting that the indicators should cover several levels. Our task now is to apply the best scientific thinking available to the problem of developing an appropriate habitat typology upon which a hierarchy of indicators, addressing both structure and function at all relevant scales, will be based. We must identify a typology that is ecologically sound, and at the same time useful for management. As a starting point to this process, we offer the following broad scheme, also represented diagramatically in Figure 1:

Level I: The Landscape/Seascape Level - This includes the entire watersheds of the Sacramento and San Joaquin Rivers, their delta, San Francisco Bay, and the near shore ocean of central California

Level II: Ecological Zones - The overall system (Level I) may be subdivided into five broad ecological "zones", with distinctly different ecological characteristics. It is of course recognized that in some cases these "zones" have overlapping and/or common elements.

A. Upland Tributaries (i.e., Bear, Feather, Yuba, Merced, etc.)
B. Mainstem Rivers (Sacramento and San Joaquin) and their floodplains
C. Delta (The legal delta and Suisun Bay)
D. The Greater San Francisco Bay (San Pablo Bay, Carquinez Straits, South Bay, and San Francisco Bay)
E. Near-shore ocean (North, South, and Western boundaries?).

Level III: Primary Habitat Types- Within each of the ecological zones listed above, a number of discrete habitat-types exist. In terrestrial systems, these are generally distinguished according to dominant vegetation types (i.e., savannah, pine forest, scrub oak, etc.). Generally, each of these is also distinguished by a characteristic assemblage of animals. In aquatic systems, the lack of readily recognizable physical characteristics often makes the task of defining distinct habitat types somewhat more formidable. Open water habitat and communities are frequently distinguished from those of the benthos. Depth distinctions are sometimes made, as are lateral (shoreline vs. midstream) distinctions. For example, the ecological zone *Mainstem Rivers and Their Floodplains* might be split into primary habitat types including *main channels*, *riparian zone*, and *floodplains*. These primary habitat types could, for some purposes, be divided further; for example *main channels* could be further broken down into *shallow water*, *substrate/benthos*, and *pools & riffles*. These sub-types can be considered a subset of the typology (as secondary habitat types), with structural and functional indicators developed for each, or, alternatively, the sub-types can be considered indicators of the primary habitat types.

***

In order to complete as much "groundwork" as possible in preparation for the second workshop, please provide your insights into question #2 on the questionnaire.

3. Developing a Recommended List of Ecological Indicators

Assuming that development of an agreed upon system typology should precede development of a recommended suite of ecological indicators, we may build upon the results of the first workshop by (1) refining the list produced, and (2) beginning to assign suggested indicators to appropriate Levels and Habitat-types. In developing a comprehensive suite of indicators, we suggest that more than one set of indicators be chosen, to encompass the various habitat types of the Bay-Delta-River system and to facilitate different aspects of management. The suite of indicators developed should cover the whole system, as well as lower hierarchical levels of biological organization, mimicking the system typology above.

Thus, we propose that one set of indicators be developed for characterizing the health of the system at the landscape/seascape level (Level I), incorporating both structural and functional components of the system. Landscape-scale *structural* components include the geographic relationship of the ecological zones to one another, whereas examples of *functional* attributes include primary productivity, hydrology, sedimentology, and the transport of nutrients and organisms. Such a set of indicators can be thought of as the *leading ecological indicators* of the system, just as certain well-chosen *leading economic indicators* reflect the health of the economy. To further refine this broad scale evaluation, a more specific set of indicators should be developed for major ecological zones within the system (Level II), and also for each primary (and perhaps secondary) habitat type within these zones (Level III). Once again, each set of indicators should represent both structural and functional components. To provide managers with information necessary for the protection of species of special concern, and to take full advantage of an extensive long-term data base already available, population-level indicators already in use should be maintained as well.

Several formats might be useful in developing such a suite of indicators: a simple list, a two-dimensional matrix (simplified from the one included in the background paper for the October workshop), and an outline. In Appendix I we have placed the indicators proposed in the October workshop into these three formats, as a suggested starting point from which to proceed. These various formats provide a tool to facilitate and organize the process of developing a suite of indicators. We encourage use of either the matrix or the outline format, because each encourages systematic coverage of each of the components of the overall framework. Various criteria (some are listed in Table 1) can be used to evaluate proposed indicators and to select a manageable number of them. It may be necessary to discuss these criteria and to choose the best ones for use at the workshop.

***

Please respond to question #3 on the questionnaire.

4. <u>Setting Target Values to Indicators</u>

Keddy et al. (1993) suggest that a range of values be set for each indicator, from tolerable to desirable level. Please begin to think about how these ranges might best be developed.

5. Workshop Organization and Format

We will base much of the organization and format of the second workshop upon careful consideration of the responses you provide to this working paper.

***

Please assist us in this process by taking the time to completing question #4 on the attached questionnaire.

Thank you for your prompt response and your continued participation in this project. Should you have any questions or comments on the project, please call Karen Levy (EDF) at (510) 658-8008, ext. 235.

Again we thank you for your active participation in this timely process.

Sincerely,

Bill Alevizon
The Bay Institute

Karen Levy

Rod Fujita

Terry Young
Environmental Defense Fund

Table 1: Criteria for indicator selection offered by conference participants and extracted from the literature.

October workshop (Keddy):
Important (represents a key function)
Cheap (efficient)
Macroscale*
Already available (historical record exists)
Necessary (educational, political, cultural)
October workshop (Breakout groups):
Mechanistic (indicative of direction for corrective action)
Responsive (not lagged)
Quantifiable (objective, explicit measurement)
Scientifically defensible
Relevant to endpoints of human interest / tied to legally defined "beneficial uses"
Noss (1990):
Capable of providing a continuous assessment over a wide range of stress
Relatively independent of sample size
Able to differentiate between natural cycles or trends and those induced by anthropogenic stress
Barbour et al. (1995):
Environmentally benign to measure
Kimmerer (1995)-- scientific defensibility:
Primary (monotonically related to an ecosystem property)
Easily interpretable
Measurable
Quantitative
Existence of a historical data record

* Discussions in the breakout groups questioned this criteria for a system as large as the Bay-Delta-River.

APPENDIX B-2: GLOSSARY OF COMMONLY USED TERMS

Glossary of Commonly Used Terms

Adaptive Management- Management that deals with uncertainty in an explicit way through a precautionary (do no harm) approach and through the use of management measures designed as experiments, with good baseline monitoring, success indicators, follow-up monitoring, and changes in management as appropriate.

Biodiversity- The number, relative abundance, variety and variability of organisms (species, populations), the ecological complexes in which they occur, and the ecological processes involved between them.

Biological Integrity (Karr and Dudley 1981)- The ability of an ecosystem to support and maintain a balanced, integrated, adaptive biological community having a species composition, diversity, and functional organization comparable to that of natural habitat in the region.

Community- A number of populations occuring at a particular place at a particular time.

Conservation (Art 1993)- Management of natural resources to provide maximum benefit over a sustained period of time.

Ecological Indicator- An attribute of an ecosystem whose state (presence or absence, quantity, level, pattern, etc.) is used to measure the health or integrity of the ecosystem.

Ecological Integrity (NRC 1992)- Maintenance of the structure and functional attributes characteristic of a particular ecosystem (or its components), including normal variability.

Ecology- The scientific study of the interactions that determine the abundance and distribution of organisms.

Ecosystem (NRC 1992)- A biological community together with the non-living parts of its environment. The boundaries of ecosystems are sometimes difficult to define; they may correspond to the relative strengths of interaction.

Ecosystem Function- Any process at some level of biological organization that contributes to the development or maintenance of the ecosystem; e.g. nutrient cycling; ecological and evolutionary processes.

Ecosystem Services- Services provided to humans by ecosystems, e.g. flood control, water supply, fisheries.

Ecosystem Structure- Identity, variety, and relationships between the elements in an ecosystem.

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Emergent Properties (NRC 1992)- Properties exhibited by the ecosystem as a whole; e.g. resilience (capacity of a system to return to baseline conditions following perturbation); persistence (ability of the ecosystem to undergo natural successional processes); verisimilitude (a broad characteristic reflecting the overall similarity of the restored ecosystem to the reference system); hysteresis (degree to which the pattern of recovery is not simply a reversal of the pattern of initial alteration).

Enhancement- Any improvement of a structural or functional attribute which increases or improves value, quality, desirability, or attractiveness of a region.

Environment (Art 1993)- The whole sum of the surrounding external conditions within which an organism, a community, or an object exists.

Habitat- The physical, chemical, and biological context within which an organism or community lives, e.g. the sediments, grasses, and water column of a marsh, the tides.

Habitat Type- A distinguishable type of place within an ecosystem. Usually recognizable by a characteristic biotic community; a unit within a typology.

Landscape- A mosaic of land forms, vegetation types, ecosystems, habitats, and land uses of a region; often consists of the watershed of a region.

Physis approach- Restoring physical processes that promote self-sustaining properties of the system.

Population- All individuals of a species occurring at a particular place at a particular time.

Pristine (Mish 1993)- Not spoiled, corrupted, or polluted.

Reclamation (NRC 1992)- A process designed to adapt a wild or natural resource to serve a utilitarian human purpose, e.g. dredging and filling of wetlands, diverging of water.

Rehabilitation- To put back into good condition or working order.

Restoration- 1. Strict, literal definition: Return to original, pre-disturbance condition; 2. Operational definition (used in this project): Facilitation of ecosystem recovery to a self-sustaining state (a state that reflects a more natural structure and function) by manipulation of the physical, biological, chemical, and even social or cultural elements of the system.

Self-maintaining system (NRC 1992)- An ecosystem that can perform all of its natural ecological functions without human intervention or dependence on engineered structures.

Typology- A classification system of types or categories; in the context of this paper, *habitat types* comprise the categories.

Watershed (Art 1993)- The total area of land surface from which an aquifer or a river system collects it water.

References cited:

Art, H.W., general editor. 1993. The Dictionary of Ecology and Environmental Science. Henry Holt and Company: New York, NY.

Karr, J.R. and D.R. Dudley. 1981. Ecological Perspectives on Water Quality Goals. Environmental Management 5(1): 55-68.

Mish, F.C., editor in chief. 1993. Merriam-Webster's Collegiate Dictionary, Tenth Edition. Merriam-Webster, Inc.: Springfield, MA.

National Research Council (NRC). 1992. Restoration of Aquatic Ecosystems. National Academy Press: Washington, D.C.

APPENDIX B-3:
WORKSHEET FOR EVALUATING INDICATORS

	CRITERIA									
	ESSENTIAL:				DESIRABLE:					
		Scientific Defensibility:								
INDICATOR:	Ecologically Relevant	Quantitative	Measurable	Easily Interpretable	Sensitive (provides an early warning)	Existence of historical data record	Benign to measure	General	Macro-Scale	Relevant to human interest
1.										
2.										
3.										
4.										
5.										
6.										
7.										
8.										
9.										
10.										
11.										
12.										

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	CRITERIA									
	ESSENTIAL:				DESIRABLE:					
		Scientific Defensibility:								
INDICATOR:	Ecologically Relevant	Quantitative	Measurable	Easily Interpretable	Sensitive (provides an early warning)	Existence of historical data record	Benign to measure	General	Macro-Scale	Relevant to human interest
13.										
14.										
15.										
16.										
17.										
18.										
19.										
20.										
21.										
22.										
23.										
24.										

APPENDIX B-4: JANUARY WORKSHOP AGENDA

Restoration of the San Francisco Bay-Delta-River: Choosing Indicators of Ecological Integrity

(Second of Two Workshops)

January 25-26, 1996

(Men's) Faculty Club
University of California, Berkeley
Berkeley, CA

Workshop Agenda

THURSDAY, JANUARY 25th

8:15 **Morning Coffee, Juice, Pastries**

8:30 **Welcome and Preliminaries** (Background on Overall Project; Review of First Workshop Results; Review of Agenda and Objectives for Second Workshop)
Bill Alevizon, The Bay Institute of San Francisco

8:45 **Introduction** (Presentation of Proposed Classification Typology: Landscape, Ecological Zones, and Habitat Types)
Dick Daniel, CALFED Bay-Delta Program

9:10 **Plenary Discussion** (Open Discussion on Typology)

9:45 **Break-Out Groups for Defining Habitat Types** (Grouped by Ecological Zone)

12:00 **Lunch**

This workshop is funded by the U.S. Environmental Protection Agency and CALFED, and is co-sponsored by The Bay Institute of San Francisco, the Environmental Defense Fund, and the Berkeley Center for Sustainable Resource Development

Workshop Agenda (cont'd)

THURSDAY, JANUARY 25th

1:00 **Plenary Session** (Results of Morning Break-Out Groups)
Terry Young, Environmental Defense Fund (EDF)

1:45 **Introduction to Afternoon Break-Out Session** (Presentation of Criteria for Indicator Selection)
Bill Alevizon, The Bay Institute
David Zilberman, Director, Center for Sustainable Resource Development(CSRD), UC-Berkeley

2:00 **Break-Out Groups** (To Recommend Indicators for Landscape, Ecological Zones, and Proposed Habitat Types)

4:30 **Progress Report on Break-Out Groups**
Terry Young, EDF
Palma Risler, U.S. Environmental Protection Agency (EPA)

5:00 **Reception**

FRIDAY, JANUARY 26th

8:15 **Morning Coffee, Juice, Pastries**

8:30 **Update of Friday's Agenda**
Terry Young, EDF

(Continue Break-Out Groups, if Neccessary)

TBA **Presentation and Synthesis of Break-Out Groups' Recommended Indicators**

12:00 **Lunch**

1:00 **Final Break-Out Group Sessions** (Objective: Revise and Finalize Set of Recommended Indicators)

2:00 **Final Plenary Session** (Concluding Comments & Discussion)
1) *"Where Are We Now?"*
-Dick Daniel, CALFED Bay-Delta Program
2) *"Where Do We Go From Here?"*
- Charles Simenstad, Coordinator, Wetlands Ecosystem Team, University of Washington

3:00 **Adjourn**
David Zilberman, Director, CSRD, UC-Berkeley

This workshop is funded by the U.S. Environmental Protection Agency and CALFED, and is co-sponsored by The Bay Institute of San Francisco, the Environmental Defense Fund, and the Berkeley Center for Sustainable Resource Development

APPENDIX B-5:
DRAFT MINUTES FROM JANUARY WORKSHOP

SUMMARY MINUTES

SECOND WORKSHOP ON "RESTORATION OF THE SAN FRANCISCO BAY-DELTA-RIVER ECOSYSTEM: CHOOSING INDICATORS OF ECOLOGICAL INTEGRITY"

JANUARY 25 - 26, 1996
Faculty Club, University of California, Berkeley

Co-Sponsored by UC Berkeley Center for Sustainable Resource Development, The Bay Institute of San Francisco, and Environmental Defense Fund With Support from the U.S. Environmental Protection Agency and CALFED Bay-Delta Program

IN ATTENDANCE: See attached participants' list.

MINUTES:

I. Introduction

Building upon the results of the first Bay-Delta workshop (in October 1995), a second workshop was held on January 25-26, 1996, with the goal of reaching broad agreement among workshop participants on:

(1) an appropriate typology (a hierarchical classification of the landscape, ecological zones, and habitat types that support different biological communities) for the purposes of ecosystem rehabilitation and management; and

(2) a suitable suite of indicators appropriate to the typology developed in (1), above, for the San Francisco Bay-Delta-River ecosystem.

The minutes of the first workshop, held on October 28 1995, are available on request from the Center for Sustainable Resource Development[1].

II. Highlights of the January Workshop

A. *Setting the Stage (initial presentations)*

- Bill Alevizon of *The Bay Institute of San Francisco and the UCB Geography Department*, summarized the results of the October workshop and provided background information for this two-day workshop. He reiterated the workshop's twofold goal, which was to develop an agreed upon typology from landscape through habitat types for the Bay-Delta-River ecosystem, and secondly, to use that typology to develop a manageable suite of indicators relevant to that ecosystem. The suite of indicators would not be definitive, but should be comprehensive enough for further refinement and development.

[1] UC Berkeley Center for Sustainable Resource Development: (510) 643-0585

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- Dick Daniel, *Assistant Director for Habitat Restoration, CALFED Bay-Delta Program*, reviewed the CALFED process and provided a progress report on the program's current efforts and timeline to identify preliminary program alternatives. He introduced a proposed breakdown of the Bay-Delta-River landscape into seven ecological zones, as proposed in the material sent out before the workshop:

  1) Upland Tributaries and Watersheds
  2) Mainstem rivers above tidal influence
  3) Tidal freshwater mainstem rivers
  4) Delta
  5) Suisun Bay
  6) Greater San Francisco Bay (west of Carquinez Strait)
  7) Near shore ocean

- During a plenary discussion on the proposed breakdown, the following questions/issues were raised:

(1) the issue of whether the proposed ecological zones for "tidal freshwater mainstem rivers" and "the Delta" were indeed separable. The separation between "Suisun Bay" and the "Greater San Francisco Bay" was also questioned. It was agreed that for the purposes of the workshop, the San Francisco Bay-Delta-River ecosystem would be broken down into <u>five</u> zones:

Upland Tributaries & Watersheds
Mainstem Rivers
Delta (including the tidally influenced freshwaters)
Greater San Francisco Bay (including South Bay, San Pablo Bay, Central Bay, and Suisun Bay)
Near-shore Ocean

(2) it was also decided that it would be up to the Greater Bay breakout group to work out proposals, if any, to distinguish different ecological zones within the Greater Bay. (Note: the breakout ended up treating the various bays as one ecological zone.)

- Dick Daniel went on to describe the objectives and aims of the workshop breakout groups, which were being given the preliminary task of identifying primary habitat types within the five ecological zones, before defining indicators. It was also noted that the classification system(s) to be used in defining each ecological zone and its habitat types would be left up to the experts in each of the five breakout groups, rather than prescribed beforehand for the groups as a whole.

- After the questions and answers, workshop participants assembled into five breakout groups in order to identify the habitat types in their respective ecological zones.

B. *Plenary Discussion and Presentation of Habitat Types Identified in First Session of Breakout Groups*

- After the breakout session, each of the five breakout group moderators summarized the habitat types for their respective ecological zones, as presented here:

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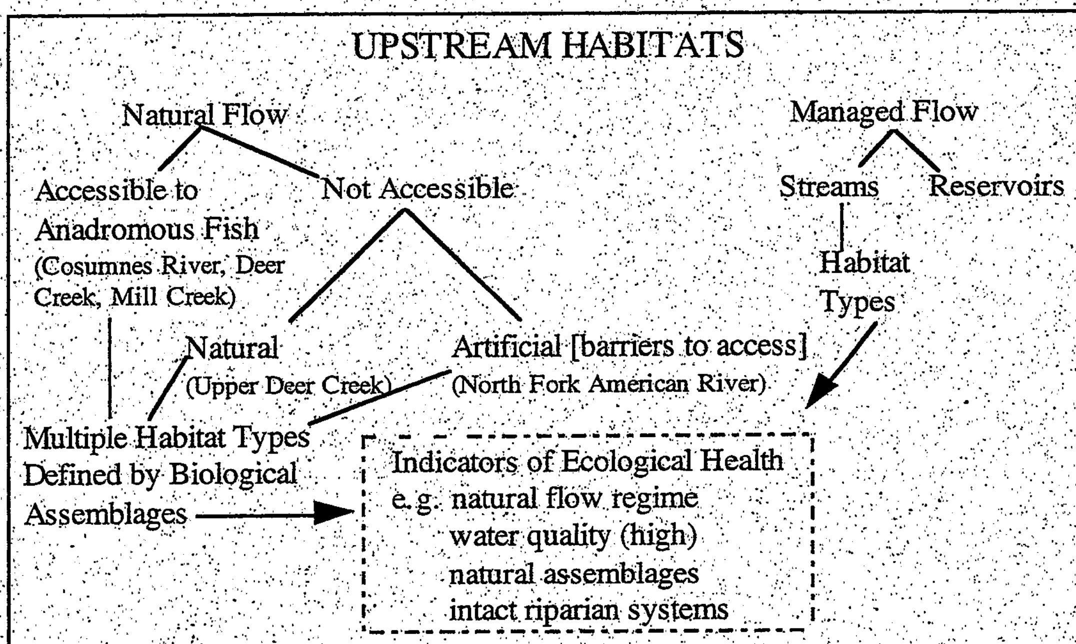
UPLAND TRIBUTARIES & WATERSHEDS (Moderator: Peter Moyle; and Participants: Susan Anderson, Sharon Gross, Judy Kelly, Tim Ramirez, H.W. Shen)

- The breakout group summarized the habitat types for Upland Tributaries & Watersheds in the following graph:



- In a written submission, Peter Moyle suggested a hierarchy leading to specific macrohabitats defined by the biota present in the ecosystem system (based on P. B. Moyle and J. P. Ellison. 1991. *A Conservation Oriented Classification System for the Inland Waters of California*. California Fish and Game 77:161-180). To get each habitat type, one works through the following scheme:

- X000 Ichthyological province
  - X1000 Standing waters
    - X1100 Ephemeral waters
      - X11xx Types of ephemeral waters
    - X1200 Permanent waters
      - X1210 Fishless lakes
        - X121x Types of fishless lakes
      - X1220 Lakes with fish
        - X122x Types of lakes with fish
  - X2000 Flowing waters
    - X2100 Ephemeral
      - X21xx types
    - X2200 Permanent
      - X1210 Fishless
        - X121x types
      - X1220...X22n0 Streams with fish
        - X122x subdivisions of types

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- Two examples of the Moyle schema (including indicators) are as follows:

A2120 Conifer snowmelt stream
Small intermittent streams in conifer forest that exist primarily while snow is melting but may have flows enhanced by seepage from bogs and meadows. Occasionally important as spawning areas for trout.
Indicators of good conditions
1. Continuous flows through snowmelt period in defined channel
2. High water clarity, pH between 6 & 8.
3. Abundance of characteristic invertebrates

A2422 Rainbow trout/cyprinid stream
Small streams of moderate gradient supporting rainbow trout and one or two species of native cyprinids and/or Sacramento sucker.
Indicators of good condition
1. Natural flow regime (no major diversions)
High spring flows, low summer flows (but permanent)
2. High summer water clarity, pH 6-8, summer temps <22 C
3. Rainbow trout dominant in terms of biomass with 3 age classes.
4. Cyprinids present, with multiple age classes
5. Foothill yellowlegged frogs common

<u>MAINSTEM RIVERS</u> (Moderator: Pete Chadwick; and Participants: Jud Munroe, Matt Kondolf, and Bruce McWilliams)

- The breakout group summarized the habitat types for Mainstem Rivers as follows:

I. Upstream areas with gravel substrate with pools & riffles

in-channel: alt pools & gravel riffles
runs/glides
plus marginal bank habitat

ex-channel: riparian corridor
bank
bottomland forest
sidechannels / oxbows / springs
F & D streams
suite of FP/terrace levels with distinctive hydrology & age of succession

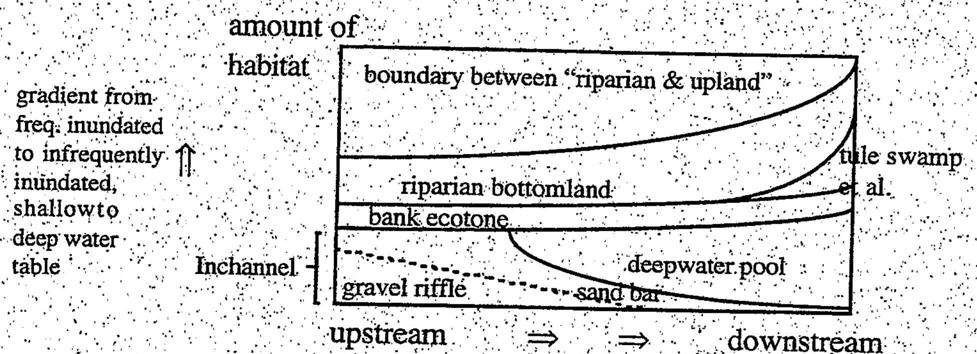
II. Active meander zone with sand & gravel substrate (with pools & riffles)

(Same as upstream areas, but broader meander zone change in sediment mix)

III. Broad low-gradient floodplain

(Same as above, but bottomland forest → freshwater marsh [seasonal flooding])

- These habitat types and their changes as a function of moving downstream and up the gradient away from the stream are summarized in the following graph:



DELTA/MAINSTEM TIDALLY-INFLUENCED RIVERS (Moderator: Bruce Herbold; and Participants: David Behar, David Fullerton, Leo Winternitz, Chuck Hanson, Patrick Coulston, Rick Soehren, Eli Ateljevich, Phyllis Fox and Phil Williams)

- The Delta ecological zone of interest is delineated in the west by Chipps Island, in the north at the confluence of the Sacramento and American rivers, and in the south at Vernalis. The breakout group summarized the five primary and fifteen secondary habitat types for this ecological zone as follows:

I. Channels
    river dominated (marked by large amounts of coarse sediment)
    transitional/inter bay areas (marked by occasional salinity intrusion, bounded by Rio Vista)
    "dead-end" sloughs

    tertiary categories for these secondary categories are water, benthos and edges. Edges may be divided into shallow aquatic region and riparian terrestrial region

II. Open Water
    shallow
    deep (rare)
    tertiary categories for these secondary categories are water, benthos and edges. Edges may be divided into shallow aquatic region and terrestrial region

III. Intertidal Marsh
    plain
    intertidal channels
    low marsh
    mudflat
    transition to upland

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IV. Non-tidal marsh
agricultural land (sustainable, non-sustainable)
vernal pools
"riparian" at back of levees

V. Flood Plain **
riparian forest
tule marsh

**Question: what is an ecologically significant definition of this region in terms of flood frequency?

<u>GREATER SAN FRANCISCO BAY (INCLUDING SOUTH BAY, SAN PABLO BAY, AND SUISUN BAY)</u> (Moderator: Fred Nichols; and Participants: Alex Horne, Randy Brown, Charles Simenstad, Lee Lehman, Dick Daniel, Roberta Borgonova, Terry Young, Karen Levy, Emery Roe)

- As a first pass, the breakout group identified and recommended the following breakdown for habitat types in the Greater Bay:

I. Water Column
-shallow
-deep

II. Mixing Zone

III. "Unvegetated" Shallows
-intertidal
-subtidal
-managed

IV. Vegetated Shallows
-intertidal
-subtidal

V. Saltwater Marshes
-natural
-managed

VI. Brackish Marshes
-natural
-managed

VII. Freshwater Marshes
-natural
-managed

VIII. Hard Substrate

IX. Small Tributary Streams

- It was also suggested that each one of the above habitat types could be located in a broader alternative classification typology proposed by Charles Simenstad, which is based on four factors (exposure, substrate, salinity, and depth):

- Marine

- Estuarine
  - -Intertidal
    - ••hard substrate
      - -vegetated
        - ••macroalgae
      - -"unvegetated"
    - ••unconsolidated substrate
      - -vegetated
        - ••emergent marsh
          - -managed
          - -natural
        - ••macroalgae
      - -"unvegetated"
  - -Subtidal
    - ••hard substrate
      - -vegetated
        - ••macroalgae
      - -"unvegetated"
    - ••unconsolidated substrate
      - -vegetated
        - ••seagrass
        - ••macroalgae
      - -"unvegetated"
  - -Water Column
    - ••shallow
    - ••deep

- Brackish
  - -Intertidal
    - ••hard substrate
      - -vegetated
        - ••macroalgae
      - -"unvegetated"
    - ••unconsolidated substrate
      - -vegetated
        - ••emergent marsh
          - -managed
          - -natural
        - ••macroalgae
      - -"unvegetated"
  - -Subtidal
    - ••hard substrate
      - -vegetated
        - ••macroalgae

-"unvegetated"
••unconsolidated substrate
-vegetated
••macroalgae
-"unvegetated"
-Water Column
••shallow
••deep

• Freshwater
-Intertidal
••hard substrate
-vegetated
-"unvegetated"
••unconsolidated substrate
-vegetated
••emergent marsh
-managed
-natural
-"unvegetated"
-Subtidal
••hard substrate
-vegetated
-"unvegetated"
••unconsolidated substrate
-vegetated
-"unvegetated"
-Water Column
••shallow
••deep

<u>NEAR-SHORE OCEAN</u> (Moderator: Rod Fujita and Participants: Bill Alevizon, Bill Kier, Ann Nothoff)

• The breakout group identified the following primary habitats for the Near-Shore Ocean ecological zones (no significant secondary habitats were noted):

I. Water column [freshwater plume needs to be considered]

II. Benthos (S=subtidal, I=intertidal)

Rocky Shore (strictly S; extensions of land)

Salt Marshes (I, primary production, nutrient transformation)

Sandy bottoms (S), [needs more analysis]

Rocky outcrops (S, in the midst of soft bottoms: rockfish habitat, inveterbrates)

Soft bottoms (benthic invertebrates [needs more analysis])

- Also noted was the zone of influence of the Bay-Delta, which extends to a plume some 25 miles out from the Golden Gate [needs more analysis]. The zone of influence is best described in terms of the species of interest: crabs, stripers, steelhead, rockfish.

- The ecological range of the Bay-Delta, with respect to salmon, extends from California to Alaska and beyond, thereby requiring coordinated management by many units. The zone of management influence of interest to CALFED, however, runs the 25 mile of water outside the Golden Gate.

C. *Introduction to Afternoon Breakout Session*

- Bill Alevizon outlined a proposed set of criteria to be used by each of the breakout groups in selecting ecological indicators for the confirmed habitat types. The selection criteria were:

(1) All indicators must be ecologically relevant, that is, closely related to or reflective of key ecological characteristics of a system or habitat.

(2) All indicators must as well be scientifically defensible, that is, quantitative, with sufficient accuracy and precision to allow ready interpretation.

(3) Exceptions to 1 and 2 fall in that class of indicators having public or policy approval, but which may have limited ecological or scientific relevance.

(4) Finally, it is desirable that indicators be: easily measurable, sensitive (i.e., quick response to stress/perturbation); based, where possible, on the historical database; benign to measure; general (i.e., applicable to different habitat types); macro-scale (indicate changes at the habitat or greater level); and useful in adding to our ability to distinguish between natural processes and anthropogenic effects.

- During the question and answer period, it was noted that indicators could also be measures of absence, e.g., the absence of a dam might be an indicator of ecosystem health.

- David Zilberman, *Director of the Center for Sustainable Resource Development*, stressed the need to link the functional and structural indicators identified in the breakout groups to ecosystem services provided by those ecosystem processes. Ecosystem structure and function were only part of the indicator selection calculus. It is important as well to identify indicators that allow policymakers and the public to choose between restoration options in more intelligent ways. It should be recognized that biologists and other environmental scientists would find the selection of service indicators difficult.

D. *Morning Plenary Session on Landscape Indicators*

- Before the breakout groups returned to their deliberations, Charles Simenstad gave a presentation on structural and functional indicators at the landscape level. His suggested criteria were that the indicator in question be:
  - applicable across habitats, ecosystems, and zones
  - directly or indirectly a measure of principal forcing processes
  - capable (scientifically, feasibly) of detecting change
  - scaled across levels of landscape organization

- referenced to baseline or target/expected levels (that encompass natural variability or noise in the system)

- On the basis of these criteria, Simenstad developed a table of recommended landscape level indicators, that was revised during the discussion period, to the following:

GOAL/VALUE/SERVICE	FUNCTION/PROCESS	STRUCTURE
Increased fish and wildlife	movement (flow) of motile/migratory organisms (spp. of concern, prey)	1. increasing connectivity of habitats (corridors) 2. dec. barriers, bottlenecks 3. inc. natural water flow regime (also relates to #7)
	feeding opportunity	4. inc. natural channel density and complexity 4a. dec. distance between "feeding stations" (habitats) 4b. dec. avg. distance btwn. nesting and foraging habitats for (resident) birds
Improve water quality	nutrient exchange	5. inc. marsh edge (#4) 6. inc. flooding duration and frequency (#3)
Restore biological integrity, resilience	biodiversity	7. inc. habitat heterogeneity 8. dec. habitat fragmentation 8a. composite metric
Stabilize shorelines	maintain & restore habitats' sediment supply	9. inc. sediment flux and distribution
Food web support	diverse sources, production, distribution of organic matter	10. inc. proportional representation and area of all habitats (#1, 2, 4, 6, 7) 11. Total landscape productivity (#13)
		12. total # of temp./physiochem. barriers to salmon (#2)
		13. sum ecological zone indicators across the landscape (inc. % of elements)
		14. sediment delivery to the estuary
		15. Morphometry of the estuary (related to tidal prism)

- A number of points were raised during the question and answer period following Simenstad's presentation:

(1) Landscape level indicators could be developed by summing ecological zone indicators across zones and/or generating unique indicators for uniquely landscape level phenomena.

(2) One suggestion of a landscape-level indicator of system integrity was the naturalness of water flow throughout the zones. Similarly, a related measure of system integrity could be the degree to which the chemical/physical barriers to fish migration were eliminated. Salmon abundance was another overall indicator that integrated many aspects of the ecosystem at the landscape level. Other possible landscape indicators included total (uninterrupted) length of rip-rap, bird diversity, total area of habitat created/restored, distance between juvenile feeding sites, and total area available for flooding. Whatever the indicators, they should include both diagnostic and prescriptive measure, even though the ability to manipulate system-wide interventions at the landscape level (particularly structural factors) may be substantially constrained.

(3) There was virtually unanimous agreement that indicators of ecosystem services (Simenstad's left-hand column) were required as a matter of priority.

(4) A comparison between Simenstad's list of landscape level indicators and those identified by participants at the October workshop indicated a high degree of congruence.

E. *Ecological Indicators Identified in Second Session of Breakout Groups*

MAINSTEM RIVERS AND UPLAND TRIBUTARIES & WATERSHEDS [merged] (Moderators: Pete Chadwick and Matt Kondolf, with Participants: Sharon Gross, Judy Kelly, Bill Kier, Bruce McWilliams, Jud Monroe, Tim Ramirez)

- The breakout group identified the following indicators for the merged ecological zone, Mainstem Rivers and Upland Tributaries & Watersheds (termed "alluvial rivers"):

[Short justifications/explanations for each biological indicator have been provided by Pete Chadwick and Matt Kondolf]

STRUCTURAL

The following indicators can be measured from sequential aerial photography and historical maps:

1) **Channel length (including side channels), and ratio of current/historical**
Channels have been shortened by meander cutoffs, straightening, and closure and filling of side channels. Result: less area of aquatic habitat, less length of bank habitat (land-water ecotone). Indicators are current length of channel and ratio of current channel length to historical (pre-disturbance) length as measured from aerial photographs and maps.

2) **Length of SRA (shaded riparian aquatic habitat) bank, length of rip-rap bank**
Vegetated banks, especially with overhanging vegetation, have important influences on aquatic habitat and constitute important riparian habitat in its own right. Migrating adults and smolts tend to utilize marginal environments, thus gaps in SRA may be barriers to migration. Length of rip-rap bank serves as an indicator of disturbance to river ecology and as indicator of gaps in SRA.

3) **Channel migration rate**
Actively migrating meandering river channels create and maintain a diversity of riparian and aquatic habitats. The migrating channel erodes high banks at the outside

of meander bends and deposits point bars on the inside of meander bends. The point bars are sites for colonization by 'pioneer' species. Over time, muddy overbank flows deposit fine-grained sediment over the point bar sands, building the floodplain elevation and permitting other riparian species to occupy the site.

4) Areal Extent of Riparian Vegetation by Class and Open Sand-and- Gravel Floored Channel

An actively migrating river will have a mix of different-aged units of riparian vegetation, as well as areas of open sand and gravel in open active channel, providing a range of habitats available to wildlife. The areal extent of various vegetation types is a measure of habitat available, the diversity of these types is a measure of habitat diversity, and the area of open sand-and-gravel bed is a measure of the potential area of aquatic habitat. Below dams, meander migration rate may slow, reducing the areal extent of pioneer vegetation species and resulting in a vegetative mix dominated by older-age stands (reducing habitat diversity), and reducing the areal extent of open sand-and-gravel bed (reducing aquatic habitat) (Johnson 1992). A related measure could be **areal extent of spawning habitat**, which would require field checking in addition to aerial photographic interpretation.

5) Area (Width) of Potential Meander Belt Migration

This is a measure of the total floodplain area (or width) within which the channel may freely migrate, without natural or anthropogenic constraints upon lateral movement, e.g., natural rock outcrops or rip-rap. This indicator thus reflects the potential for channel migration and thus potential for maintenance of habitat diversity described above. The present value of this indicator can be compared with historical values to indicate the degree of alteration.

6) Number of unscreened diversions

The number of unsreened diversions provides an index of the number of fish diverted with the water being taken out of the river. It is an imprecise index because of factors such as differences in the sizes of diversions and variations in fish losses associated with location of diversions.

The following indicator would require aerial photography at appropriate times during floods or application of hydraulic models to predict inundation levels at various discharges:

7) Area flooded by 2-year and 10-year floods

This indicator reflects the area of floodplain still actively connected with the riverine hydrology, and by comparing present with historical values, can indicate the degree to which connectivity has been reduced as a result of dam-induced flow changes or levee construction.

<u>FUNCTIONAL</u>

8) Abundance of Anadramous Fish

The abundance of the various species of anadramous fish integrates the overall effects of habitat quality on the most important group of fishes in the system.

9) Survival Rate of Outmigrant Anadramous Fish

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Survival rates of outmigrants integrate the effects of overall habitat quality an various species of fish. They are indicative of habitat conditions in the river reach they are measured over, while overall abundance of anadramous fish integrates effects over the entire habitat of the species.

10) Toxics

Concentrations of toxics would indicate potential stresses on populations. considerable interpretation is needed due to the wide diversity of toxics, each with different and often uncertain effects on any given species and often different effects on different species.

11) Dissolved Oxygen

Concentrations of dissolved oxygen indicate potential effects of an essential element for almost all aquatic organisms.

12) Number of Outmigrants by race (e.g., salmon)

The number of outmigrants reflects the combined effect of the number of spawning adults and the effects of habitat conditions on the survival of the eggs and young. While the number of outmigrants is easier to measure than survival rates, it is a less satisfactory indicator of habitat conditions due to its reflecting both adult abundance and survival.

13) Water Temperature

Each aquatic species has specific water temperature requirements which often vary at different stages during the life cycle. Thus water temperature is often an indicator of a critical environmental condition, but one that is specific to each species and life stage.

This indicator can be measured from gauge records of the US Geological Survey or dam operators:

14) Deviation from Natural Hydrograph

The specific indicators proposed are the *pre- and post-dam floods* as measured by the Q_{maf}, Q_2, Q_{10}, *and* Q_{20}, respectively, the mean annual flood and the floods with return periods of 2, 10, and 20 years, each computed for the period of record before dam closure and after dam closure. In some cases, the record should be divided into three or more periods to reflect distinct stages in dam construction in the basin, such as on the Mokelumne River, where the flood regime differs for the periods before Pardee Reservoir, after Pardee but before Camanche Reservoir, and after Camanche Reservoir. Other specific indicators proposed are the *average monthly flows* (Q_{av}) *for August, September, October, and November*, which provide a measure of baseflows and flows for upstream migrating adult salmon, and the *average monthly flows* (Q_{av}) *for May, June, and July*, which provide a measure of flows available to out-migrating smolts. These flows must be measured along the entire reach over which salmon must migrate, so that effects of downstream diversions are taken into account in the analysis.

This indicator can be measured from results of a sediment budget for pre- and post-dam conditions:

15) Deviation from the Natural Sediment Budget

Specific indicators under this category might be percentage of pre-dam supply of gravel and sand-sized sediment delivered to the reach, or a measure of sediment supply in relation to river transport capacity, which below a dam is likely to reduced along with sediment supply.

The following indicator is difficult to specify or measure because of the strong temporal and spatial variability displayed by the relevant processes, and the difficulty and expense of obtaining suitable data. However, a basic water budget of amounts extracted from alluvial aquifers, amounts of irrigation water applied to floodplain fields with potential to recharge bank inflow to the channel, and evapotranspiration from fields would provide a framework within which more site-specific data collection schemes could be designed.

16) **Groundwater Regime**
The interactions between alluvial groundwater and streamflow can be extremely important for aquatic habitat in maintaining baseflow, in creating suitable conditions for salmonid spawning, and in supporting the invertebrate community in the hyporheic layer.

- It was noted that a full-fledged suite of indicators on groundwater/river interactions might require installation and operation of observation wells.

<u>DELTA/MAINSTEM TIDALLY-INFLUENCED RIVERS</u> (Moderator: Bruce Herbold and Participants: David Behar, David Fullerton, Leo Winternitz, Chuck Hanson, Patrick Coulston, Rick Soehren, Eli Ateljevich, Phyllis Fox and Phil Williams)

- The indicators identified by the breakout group at the ecological zone scale are:
  - desirable, sustainable harvest levels of non-toxic fish
  - non-consumptive recreation hours
  - surveys of satisfaction
  - total sediment accumulation/ marsh accumulation
  - increased populations of desirable species
  - increases in primary and secondary productivity
  - smolt survival through zone
  - dispersal of estuarine species & landscape geographic distribution
  - reduced toxicity of water
  - predictability of community structure (consistent rank abundance)
  - reduction of flood risk (taking some more susceptible agricultural lands out of production, decrease risk)
  - index of native species abundance
  - number of introduced fish and inverts per year
  - diversions
    - ratio of screened/unscreened
    - total number of diversions
    - % of inflow diverted
  - number of exceedences of water quality standards per year

- The indicators identified by the breakout group at the habitat-type scale are summarized in the following table:

Habitat	Indicator	Service
channel, edge	miles of riprap or degraded bank replaced by habitats of higher wildlife value such as SRA	aesthetics, nesting, food supply for organisms, biological filter
channel, edge	area of berm islands (or length)	fish, bird, mammal, invertebrate habitat, sediment trap, food supply for organisms
channel, water	number of barriers to fish passage; fish migration	fish migration, habitat access, predation
channel, water	fish counts (also, % of sport fish of legal size that have reasonable toxin levels)	not considered
channel, water	net positive flows during migration	
channel, water	reduction in applications of toxic materials (e.g. pesticides)	water quality, human health -- water and organism consumption, survival, fitness and condition of fish bird, mammal and invertebrates, trophic dynamics (food web effects), aesthetics
channel, water	number of unscreened diversions or functional equivalent measure of fish entrainment (and) total diversions	survival of organisms
channel, water	area of connected emergent vegetation (tidally influenced)	habitat access, sediment trap, access to food, predation effects
channel, dead-end slough	length of dead-end slough (tidal)	fish habitat
channel, dead-end slough	number of branches	
open water	area and linear edge of emergent vegetation (or) diversity and stature of emergent vegetation	
intertidal marsh	area of evolved marshland (large marsh in which channels develop at a minimum rate)	biodiversity (increased quality of marshland)

Habitat	Indicator	Service
intertidal marsh	area of evolved marshland with buffer (at least certain distance from agricultural or urban areas)	
non-tidal wetland, agricultural	amount of food (Kcal) produced which is available to waterfowl (may be separated by source into agricultural spoils and natural production) **	
non-tidal wetland, agricultural	area of land less than one foot deep in December or March	
vernal pools	area of natural vernal pools protected	
non-tidal wetland, riparian not adjacent to water	length and width of riparian forest	
floodplain	length and width of riparian forest	
floodplain	area of two/other -year frequency flood plain that interacts with river floodplain	
floodplain	width of active meander belt	

GREATER SAN FRANCISCO BAY (INCLUDING SOUTH BAY, SAN PABLO BAY, AND SUISUN BAY) (Moderator: Fred Nichols; and Participants: Alex Horne, Randy Brown, Charles Simenstad, Lee Lehman, Dick Daniel, Josh Collins, Susan Hatfield, Terry Young, Karen Levy, Emery Roe)

- The breakout group recommended the following indicators for the Greater Bay ecological zone and habitat types identified above:

***Numbers in parentheses signify rating of the indicator [1=high priority, 3=lower priority. Letters refer to the zonal or habitat level at which the identified indicator is a structural and functional indicator (A= zone, structure; B=zone, function; C=habitat/community, structure; D=habitat/community, function; E=habitat/population, structure; F=habitat/population, function). Indicators are categorized (in most cases) by the service they provide (e.g. food web support)].

ZONE (LANDSCAPE)

- vegetative patch structure (2, A)
- connectivity (at several scales) (1, A)
- distribution of subordinate estuaries (3, A)

- sediment supply (2, B)
- freshwater flow variations (1, B)
- salinity (1, A)
- residence time of juvenile anadromous fish (2, B)
- number and/or biomass of newly introduced species (3, A)
- distribution of pollutants (2, B)
- (some measure of support of resident fish & wildlife) (2)

WATER COLUMN (SHALLOW)

FOOD WEB SUPPORT

- diatom : flagellate ratio (3, C)
- chlorophyll *a* (as a measure of primary production) (1, D)
- turbidity (as a measure of primary production) (1, D)
- biomass of planktivorous fish (3, D)
- water column stratification (1, C)
- juvenile herring growth rate (3, F)
- density and diversity of larval fish (1, C)

COMMERCIAL & RECREATIONAL FISHERY

- catch per unit effort (2, D)

FISH AND WILDLIFE HABITAT

- diving bird abundance and diversity (+ some success metric) (1, C)
- harbor seal abundance (3, E)

WATER COLUMN (DEEP)

See "unvegetated" subtidal shallows

MIXING ZONE

- X_2 (1, C)
- excedence of X_2 (C)

"UNVEGETATED" INTERTIDAL SHALLOWS (MUDFLATS)

- area (1, C)

FISH & WILDLIFE SPECIES SUPPORT

- prey abundance & distribution (3, C)
- wildlife sign (incl. bird feces, bat-ray divets)- rate/time (3, D)

SOURCE OF ORGANIC MATTER

- chlorophyll *a* on sediments (3, D)

SEDIMENT SUPPLY

- deviation from expected elevation (3, D)

SHELLFISH HARVEST

- fishery success rate (1, D)

"UNVEGETATED" SUBTIDAL SHALLOWS

FOOD WEB SUPPORT

- benthic shrimp & mysid biomass/density (1, C)
- mollusc biomass/density (1, C)

FISH & MACROINVERTEBRATE HABITAT

- change in pollutant levels in sediments (2, D)

VEGETATED SHALLOWS (SUBMERGED AQUATIC VEGETATION (SAV) & MACROALGAE)

- area (1, A & C)
- epiphyte load (3, C)
- seagrass shoot density (2, E)

PROVIDES FISH AND WILDLIFE HABITAT & FOOD-WEB SUPPORT

- herring spawn (egg density) (1, E)
- macroalgae and SAV coverage (2, C)
- seagrass shoot density (2, E)

SALT MARSHES/BRACKISH MARSHES/FRESHWATER MARSHES

- acreage (1, C)

USE TIDAL MARSHES TO IMPROVE WATER QUALITY AND FISH FORAGING

- channel density (relative to sources of pollution, salinity zones, fish distribution, elevation) (1, A& C)
- proportion of *Spartina alterniflora* in the marsh community (2, C)
- pollutant concentrations (2, B & D)

TIDAL MARSHES AS RESIDENT WILDLIFE HABITAT

- habitat metrics for each ecologically important species (e.g. marsh plant shoot height/density) (2, C)
- change in population of ecologically important species (1, F)
- complexity of elevational structure (topographic complexity) (2, A & C)
- diversity of plant species (2, C)
- channel density (1, A & C)

PROTECTION OF SHORELINE FROM EROSION

- width of marsh relative to wave energy (fetch and boat wakes) (3, C)
- change in position of marsh edge (towards shoreline (-); away from shoreline (+)) (1, D)
- channel density (1, A & C)

SUPPLY OF ORGANIC MATTER (DISSOLVED OR PARTICULATE)

- net transport of organic matter at habitat interfaces (3 (b/c of complexity & expense), B)

- amount of marsh-derived organic material in bay organisms (3, B)
- channel density (1, A & C)

PROMOTE NUTRIENT CYCLING
- channel density (1, A & C)
- sedimentation rate (2, D)

SUPPORT OF MIGRATORY SPECIES
- ratio of non-vegetated : vegetated marsh (1, C)
- channel density (1, A & C)

MANAGED MARSHES

SUPPLY OF RESIDENT WILDLIFE HABITAT
- acreage (1, C)
- diversity of plant species (2, C)
- water quality/supply (3, D)
- habitat complexity (1, C)
- proximity to & amount of neighboring sanctuaries and natural habitats (1, C)

HARD SUBSTRATE

SUPPLY OF FISH & WILDLIFE HABITAT
- herring spawn (density of eggs) (1, E)
- proximity to "holding areas" (e.g. for herring) (2, C)
- amount of natural hard substrate (1, C)

SMALL TRIBUTARY STREAMS

SUPPLY OF FISH HABITAT
- number of young, outmigrating anadromous salmonids (2, C)
- number of "barriers" to fish passage (1, C)
- area of brackish water habitat at stream mouths (1, C)

<u>NEAR-SHORE OCEAN</u> (Presentation by Bill Alevizon)

- Within the habitats identified, indicators are needed to evaluate and monitor:

I. Structural integrity of shoreline and benthic habitats

II. Water Quality (particularly toxics; levels in fish and mussel tissue)

III. Sustainable harvest levels

- It was recommended that substantially more work would need to be done to identify suitable indicators for this ecological zone.

F. *Concluding Remarks*

- Dick Daniel thanked the group for refining and extending the work of the first workshop in October. He noted that the information provided during the workshops would help CALFED:

  (1) refine restoration goals (since some of the indicators are easily translated into goals);

  (2) better define and validate the restoration alternatives to be developed by the CALFED Program;

  (3) guide near- and longer-term research that is necessary;

  (4) develop a vision for restoration of the landscape and for eco-zones;

  (5) focus the scientific debate that is going on with respect to indicators of ecosystem health; and

  (6) design the eventual implementation and monitoring programs.

He underscored the importance of having different levels of indicators and different audiences for those indicators. Some people are interested primarily in diagnostic indicators, others in prescriptive ones, while others are much more in interested in indicators of services, though indicators may well overlap across the areas of interest.

- In speaking of follow-up activities from the workshop, he noted the need to further investigate the literature on more formal classification schemes, so that the proposed habitat and zones proposed during the workshop will have strengthened scientific credibility. In this regard, he also noted that not all of those who were invited attended the workshop. Another area of followup would be to assess (1) existing monitoring programs to determine the degree to which their indicators match up with those proposed at the workshops and (2) the applicability of the historical database to designing future programs. Finally, there was need to follow up David Zilberman's recommendation that indicators of ecosystem services be developed as a matter or priority.

- After Dick Daniel's presentation, comments were made suggesting that such workshops be opened to the wider public so they can see for themselves how complex the restoration process and science underlying it are.

- Charles Simenstad then stressed the following points:

1. *Communicating Results.* The importance of translating the results of the workshop and CALFED process into a better understanding of complex concepts by managers and society. In this way, the conceptual models of the experts have a chance of

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illustrating the trade-offs posed by trying to meet different ecosystem services. These models, albeit cartoons, can influence the public's understanding, if translated into terms they understand.

2. *Apples & Oranges.* The potential difficulty in applying inconsistent (uncommon levels/attributes of organization) typologies. The challenge ahead is to integrate the proposed habitat types and ecological zones across the whole system, such that the indicators can be applied and mapped in ways that relate to and/or scale up to the landscape level.

3. *Encapsulate variability!* While variability invariably exists in estuarine systems, most breakout groups were able to encapsulate this variability into their suite of proposed indicators. Indeed, variability can be used explicitly as an indicator, as in the case of flow variability. The challenge is to characterize or quantify what is variability and what is noise around the indicator (target) levels chosen.

4. *Self-Sustainability.* Promote the concept of self-sustainability in ecosystems. The ultimate goal is for minimal or no human investment in the long-term maintenance of the ecosystem, where the means to achieve this goal lies in adaptive management strategies.

5. *The challenge is worth it.* The CALFED process is one of the first exercises of its kind on such a landscape-wide, large scale system, where the restoration effort is geared to managing reversible ecosystem degradation.

• David Zilberman concluded the workshop by emphasizing the interest the Berkeley campus had in workshop issues, as best witnessed by the campus-wide Bay-Delta Working Group. The Group was in the process of preparing a campuswide proposal to be submitted to the CALFED Program, and efforts such as the workshops illustrated how linking biology and policy was absolutely imperative for the success of future Bay-Delta-River interventions.

APPENDIX B-6: LIST OF PARTICIPANTS AT THE JANUARY WORKSHOP

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